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WATER QUALITY INVESTIGATIONS, LAKE MICHIGAN BASIN. PHYSICAL AND CHEMICAL QUALITY CONDITIONS

Federal Water Pollution Control Administration
Chicago, Illinois

January 1968

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WATER QUALITY INVESTIGATIONS

PB 216 141

LAKE MICHIGAN BASIN

PHYSICAL AND CHEMICAL QUALITY CONDITIONS

A TECHNICAL REPORT CONTAINING BACKGROUND DATA FOR A WATER POLLUTION CONTROL PROGRAM.

NATIONAL TECHNICAL INFORMATION SERVICE

FEDERAL WATER POLLUTION CONTROL ADMINISTRATION

GREAT LAKES REGION, CHICAGO, ILLINOIS

JANUARY 1968

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LAKE MICHIGAN BASIN

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UNITED STATES DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
Great Lakes Region Chicago, Illinois

GPO 806-484-1

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INTRODUCTION

This report presents the physical and chemical results of a comprehensive study of Lake Michigan waters conducted by the Great Lakes-Illinois River Basins Project from April 1962 to July 1964.

The study was conducted through the collection of appropriate samples during a series of 20 cruises made on the Lake by laboratory-equipped vessels. Analyses which required immediate attention were carried out aboard ship. Other analyses were performed at the GLIRB Project laboratories. These procedures are described later.

The purpose of this study was to determine the present physical and chemical water quality and to describe those areas of the Lake which exhibited significant water quality degradation.

PARAMETERS, DEFINITIONS, AND SIGNIFICANCE

Parameters

The parameters which were considered and reported in subsequent sections of this report are: ammonia nitrogen; total soluble phosphate; silica; dissolved oxygen (DO); phenols; methylene blue active substances (MBAS); biochemical oxygen demand (BOD); hydrogen ion concentration (pH); dissolved solids; nitrate; sodium; potassium; calcium; specific conductance; alkalinity; magnesium; sulfate; chloride; and toxic metals (copper, cadmium, nickel, zinc, lead, and chromium). Certain of these parameters were found to have practically no variation, either geographically or with time, on all of the lake samples analyzed to date, whereas others exhibited detectable changes in some areas and seasons. The parameters showing significant changes were ammonia nitrogen, nitrate nitrogen, total soluble phosphate, silica, DO, specific conductance, phenols, and BOD. Of these, the first three cited exhibited appreciable variation in all areas of the Lake. Deepwater samples showed fewer variable parameters than did the inshore samples, and the greatest variability was shown in the harbor areas.

Definitions and Significance

Nitrogen: Ammonia, Nitrate, and Nitrite

Nitrogen in its chemically combined forms is a necessary constituent to the life cycle of aquatic flora and fauna. If it is present in the aquatic environment with phosphates in moderate concentrations, accelerated growths of algae can result. Ammonia in high concentrations, above 2 to 2.5 mg/l and under alkaline pH conditions (pH 8-8.5) (1, 2)*, is a substance toxic to many forms of aquatic life (3). At all levels, it is an increased burden to municipal water treatment because of its high chlorine demand. It is an indicator of sewage pollution because of its presence in human and animal waste discharges, and may be a significant constituent in some industrial wastes. Amines and cyanides have toxic properties peculiar to specific compounds containing these chemical groupings. Nitrate nitrogen (3) has been implicated as a cause of methemoglobinemia in infants; a limit of 45 mg/l of nitrate (as nitrate) has been recommended in the U. S. Public Health Service Drinking Water Standards (4).

Total Soluble Phosphate

Phosphate, like the nitrogen compounds, is a necessary nutrient for biological activity. Its presence in water is not considered harmful

*Numbers in parentheses refer to references listed at end of report.

to human health. However, excessive concentrations of phosphate, coupled with other favorable conditions such as abundant nitrogen supply, optimum temperature and sunlight, can result in dense algal blooms. These excessive growths affect the quality of water, interfere with water treatment operations, increase taste and odor problems, cause unsightly scums and decaying matter, and create problems due to fluctuations of dissolved oxygen. Concentrations of phosphates between 0.03 and 0.3 mg/l are needed to stimulate algal growth according to various authors (5). Sawyer (6) states that "nuisance conditions can be expected when the concentration of inorganic phosphorus equals or exceeds 0.01 mg/l" (0.03 mg/l as phosphate).

Phosphate enters the water environment in treated sewage because it is not normally removed by conventional treatment processes. It is normally present in human and animal waste products. Synthetic detergents contain high concentrations of phosphates and have further increased the quantities discharged. Phosphate is also present in surface runoff, particularly from fertilized fields, and may be a component of the effluent from certain industrial processes.

Silica

Silica appears in water as a solution and as finely divided or colloidal suspended matter. Most silica probably occurs in water as a result of contact with deposits of minerals high in silicate, such as feldspar, kaolinite, etc. The concentrations of silica normally found in water have no significant physiological effects. However, since diatoms require silica for manufacture of their skeletons, it would follow that the availability of the substance should be one of the factors limiting the production of large crops of this important group of plankton. The presence of diatoms in large numbers interferes with water treatment processes, especially the clogging of filters.

Dissolved Oxygen (DO)

Dissolved oxygen is one of the most important constituents of a natural water. The existence of desirable aquatic life is dependent on the presence of adequate levels of oxygen at all times. The solubility of oxygen in water is low and is affected by both physical and biochemical forces. The maintenance of satisfactory levels depends upon the equilibrium established between the forces utilizing oxygen and those contributing it.

Oxygen is utilized by aquatic organisms during the processes of respiration. It is replenished from the atmosphere by physical forces and can also be added through photosynthesis by algae and higher aquatic plants. When organic pollution enters an aquatic environment, the balance between consumption and contribution is upset. The bacteria present in water or introduced with the pollution begin active degradation of the organic matter,

multiply rapidly in the process, and consume the oxygen dissolved in the water. If they use oxygen at a great enough rate, the resultant oxygen in the water may not be sufficient to support aquatic life. In polluted waters, these conditions are particularly in evidence during warm weather when the rate of oxygen consumption is increased and the ability of water to hold oxygen in solution is decreased.

Biochemical Oxygen Demand (BOD)

The introduction of organic waste into water - whether the waste originates from domestic sewage, industrial processes, land runoff, or any other source - initiates a chain of events involving the organic material, micro-organisms accompanying it, and the natural biota present in the receiving water. Organic matter is rapidly utilized as food by those organisms capable of converting it; the net result of this action is consumption of dissolved oxygen. Because control of dissolved oxygen is important in water quality management programs, a means of measuring the oxygen-consuming potential of wastes is necessary. The test commonly used for this purpose is the BOD test.

The BOD test measures a biochemical reaction rather than a well defined chemical reaction; it involves observation of oxygen usage by micro-organisms which convert unstable organic matter into cellular material and respiratory products. Toxic substances, if present, adversely influence this test.

Phenols

Phenolic material, which includes phenols, cresols, and xylenols, when found in water is usually the result of pollution by industrial wastes (7). Phenols are widely used in the synthesis of many organic compounds. Waste products from oil refineries, coke ovens, and chemical plants may contain high concentrations.

Lethal concentrations for fish are related to the species, duration of contact, temperature, and other conditions. Experimental data, however, show that 5.0 mg/l would be toxic to most fish (8), and some of the chlorinated phenols exhibit toxicity in concentrations as low as 0.2 mg/l (9).

Very low concentrations of phenols will impart a disagreeable taste to water when chlorinated. The chlorophenols produced by the addition of chlorine have a more disagreeable taste and odor than the parent substance. Thresholds of taste and odor for chlorophenols range from 0.001 to 0.02 mg/l (10). The drinking water standards of the U. S. Public Health Service have set the upper limit for phenol at 0.001 mg/l because of its objectionable taste following chlorination.

Methylene Blue Active Substance (MBAS)

Methylene blue active substances are anionic surface-active agents. These surface-active agents have been a common ingredient of many commercial synthetic detergents for a number of years. Their function in detergents is to impart foam and reduce surface tension to aid in the removal of dirt particles during the cleaning process. Until just recently, the most widely used surface-active agent was the group of anionic alkyl benzene sulfonates, generally termed ABS. These compounds are very resistant to biological degradation and persist in water many miles from the point of entrance. MBAS is believed to be non-toxic to man (11, 12) in the concentration found in contaminated water. Because they produce unsightly, persistent foams and cause water to exhibit undesirable taste, the concentration limit for drinking water used on interstate carriers has been set at 0.5 mg/l (4). These compounds have now been replaced in commercial detergents by surface-active agents that are biologically degradable so that their presence in the aquatic environment can be minimized, where adequate treatment is provided.

Hydrogen Ion Concentration (pH)

pH is defined as the logarithm of the reciprocal of the hydrogen ion concentration or, more precisely, of the hydrogen ion activity - in moles per liter (9). pH 7 is the neutral point, or dividing line between an "acid" and an "alkali"; pH values below 7 indicate an acid condition; values above 7 indicate an alkaline condition. Each unit change in pH indicates a tenfold change in hydrogen ion concentration; e.g., pH 6 is 10 times stronger than pH 7, and pH 5 is 100 times stronger than pH 7, in terms of hydrogen ion concentration.

The pH value of water is significant for several reasons. Acidic waters (low pH values) disrupt biological activity, cause corrosion of steel and concrete, intensify the effect of toxic materials such as sulfides and cyanides, interfere with water plant coagulation practices and tend to add undesirable iron and manganese to the water. Alkaline waters (high pH values) also disrupt biological activity, precipitate iron, calcium and magnesium, and increase the toxicity of ammonia and amines.

Dissolved Solids

The dissolved solids test measures the concentration of dissolved material present. This includes both organic and inorganic matter. Excessive dissolved solids in water can be unpalatable and increase the cost of water treatment for many uses. The Drinking Water Standards of the U. S. Public Health Service recommend the rejection of sources providing water containing over 500 mg/l of dissolved solids (if another water source is available) because of a noticeable saline taste, and possible cathartic effect on many individuals.

Sodium

Sodium is an alkaline metal, the salts of which are very soluble in water and tend to remain in solution. The use of sodium salts is very common in industry, and industrial wastes may contain large quantities of the element.

Sodium salts are not particularly significant in drinking water, except for those persons having abnormal sodium metabolism. It has been disclosed (13) that sodium in excess of 200 mg/l is significant to those suffering from high blood pressure.

Potassium

Potassium, an alkaline metal, is abundant in the earth's crust, yet its content in natural waters is usually small. In low concentrations it is essential for plant and animal development (14), but must be maintained in proper balance with phosphorus.

Potassium stimulates plankton growth (15), but is otherwise insignificant unless found in concentrations above 400 mg/l, a level considered toxic to fish (16).

Calcium

Calcium, an alkaline earth metal, is one of the constituents which produces hardness in water. However, the amount of calcium usually found in hard waters is less than the daily nutritional requirement. Hardness is ordinarily considered undesirable because of scaling and reduced heat transfer in heating and cooling systems and because of increased soap consumption. Research (17) has demonstrated that there may be a relationship between the hardness of drinking water and a reduction in cardiovascular disease.

Magnesium

Magnesium, like calcium, is a hardness-producing mineral and contributes to the hardness effects discussed under calcium. It is not known to produce toxic effects, although in high concentrations magnesium salts have a pronounced laxative effect.

Specific Conductance

Specific conductance yields a measure of a water's ability to carry an electric current and is therefore an indication, within rather wide limits, of the ionic concentration of the solution. The amount of dissolved matter in a sample may often be estimated by multiplying the specific conductance by an empirical factor. This factor may vary from

0.55 to 0.9 depending on dissolved substances and the temperature of the water.

Waters polluted by brines and chemical saline wastes will produce a relatively high level of conductivity. This gives rise to an increase in osmotic pressure which has a harmful effect on living organisms. Wide variations in total salinity or in the concentrations of individual salts can have far-reaching effects upon water fauna, resulting even in the elimination of the species (18, 19).

Alkalinity

Alkalinity is defined as the capacity of a water to neutralize hydrogen ions and is expressed in terms of an equivalent amount of calcium carbonate. Alkalinity is caused by the presence of carbonates, bicarbonates, hydroxides, and, to a lesser extent, by borates, silicates, phosphates, and organic substances.

In itself, high alkalinity is not considered detrimental to man, but it is generally associated with high pH values, hardness, and excessive dissolved solids, all of which may have an adverse effect on the quality of the water.

Sulfate

The sulfate anion is a component of the dissolved ionic solids present in most surface waters. Large quantities of sulfates are often added to the aquatic environment as industrial wastes, especially as waste pickle liquor from steel mills. Sulfates in combination with sodium or magnesium can produce a laxative effect. To control this effect, a maximum of 250 mg/l has been recommended for drinking water.

Chloride

Although chlorides are present to some extent in most surface waters, they are also associated with man's activities, since the chloride anion is a component of human waste and is widely used in many industrial processes. Chlorides can impart a salty taste to drinking water and render it unpalatable. Many waters are unsuitable for domestic use, irrigation and industrial processes because of high chloride content. The Drinking Water Standards of the U. S. Public Health Service recommend the rejection of sources providing water containing over 250 mg/l chloride if other water of better quality is available. It is not removable by conventional water and waste treatment methods. Increased chloride concentration would imply deterioration in water quality for many beneficial uses.

Toxic Metals

The U. S. Public Health Service Drinking Water Standards (4) limit the concentration of certain metals in drinking water because of potential toxic properties to humans. These limits are as follows: arsenic, 0.05 mg/l; barium, 1.0 mg/l; cadmium, 0.01 mg/l; chromium, 0.05 mg/l; lead, 0.05 mg/l; selenium, 0.01 mg/l; and silver, 0.05 mg/l. The presence of any of these elements in excess of the concentration listed shall constitute grounds for the rejection of the water supply.

U. S. Public Health Service Drinking Water Standards (4) provide tolerance limits for metals that, if exceeded, can constitute grounds for rejection of water supplies if other suitable supplies can be made available. These are as follows: arsenic, 0.01 mg/l; copper, 1.0 mg/l; iron, 0.3 mg/l; manganese, 0.05 mg/l; and zinc, 5.0 mg/l. The basis for rejection in this tolerance list is not toxicity in all cases but is also related to consumer acceptance. In addition to human toxicity, some of these metals are toxic to aquatic life and can play an important part in the biological character of the aquatic environment.

In the studies of the Lake Michigan Basin, six metals, considered as having toxic properties in relation to beneficial water uses, were studied in detail. These were copper, cadmium, lead, chromium, nickel, and zinc.

Copper occurs in natural waters only in trace amounts. Excessive quantities are generally the result of pollution, attributable to the corrosive action of water on brass or copper piping, to industrial wastes, or to the use of copper for the control of undesirable plankton organisms. Copper in water may be detrimental for some industrial uses and has been found toxic to a wide variety of aquatic organisms, including bacteria and fish (3).

Cadmium is one of the least abundant metals present in the earth's crust and is rarely found in natural waters. It is invariably present in zinc to some extent. Its uses are limited principally to industrial applications, therefore quantities found in water are the result of industrial pollution. It has been found to be toxic to man when ingested, therefore its presence in water is a definite health hazard. It is also toxic to aquatic life, including fish (3).

Lead occurs in natural waters only in trace amounts. Excessive quantities are generally the result of pollution, attributable to the action of water on lead pipe and industrial wastes. Lead is toxic to man in low concentrations and is accumulative. It is also toxic to aquatic life, including fish (3).

Trace concentrations of chromium are found in some natural waters, but excessive concentrations arise from its industrial uses. It is extensively used in electroplating, tanning, paint manufacture, and other industries, and is used to control corrosion in cooling water systems of power plants. Its toxicity to humans when ingested in water is subject to some question, but because of its pronounced toxicity and carcinogenic properties when present in other paths of exposure, the limits set for drinking water reflect these considerations as a factor of safety. Its toxicity to aquatic life covers a broad range, being toxic to some of the smaller organisms at levels as low as 0.05 mg/l (3).

Nickel is not a common constituent of natural waters, its presence being related to industrial waste discharges. Its toxicity to humans is low and is not considered to be a health hazard in concentrations usually present in natural waters. It is toxic to aquatic life, but less than copper or zinc (3).

Zinc is present in most surface and ground waters only in trace amounts, its presence being related to the corrosive action of water on galvanized piping and to industrial wastes. Its toxicity to humans is low when compared with the other metals. It is toxic to aquatic life, but less than copper (3).

LABORATORY PROCEDURES

Sample Preservation

After samples were collected, each sample was divided (on shipboard) into half-gallon portions according to substances to be analyzed and preservation requirements. Preservatives added to each half-gallon polyethylene bottle of sample were as follows:

1. For phosphate analysis - 10 ml of chloroform.
2. For nitrogen analysis - 1.8 ml of sulfuric acid.
3. For phenol analysis - 20 ml of 10 percent copper sulfate and 20 ml of phosphoric acid.

On Cruises 5 and 6, BOD analyses were performed on shipboard. On the other cruises, BOD samples were packed in ice at the time of collection and returned to Project headquarters for analysis. The average time in transit for these samples was four hours, and the longest time five hours.

Special preservation measures were not necessary for the sample portions used for mineral analyses.

Analytical Methods

The physical and chemical data included in this report were obtained, unless otherwise indicated, by following the procedures published in "Standard Methods for the Examination of Water and Wastewater," 11th Edition, 1960, referred to throughout this report as Standard Methods. While many methods may be used in water analysis, those described in the Standard Methods have been selected for this study because the procedures are supported by collaborative studies of capable analysts, throughout the nation, who have demonstrated the methods to be accurate and reproducible within specified limits.

Minor modifications have been made on some of the methods used, when they could better accomplish the purpose for which the procedure was applied. Before adopting any change or modification, however, many repetitive analyses were made to determine the precision of the modified method and also its agreement with the Standard Methods.

To assure continually reliable data, reference standards, of known composition, and many blanks were analyzed simultaneously with all tests.

A skeleton outline of tests performed is presented below. Where the tests conform strictly to Standard Methods only the pages wherein the

procedure may be found are cited, but where modifications or changes are made these have been described in detail. Tests marked by asterisks were performed on shipboard.

Nitrogen--Ammonia and Organic

Free ammonia nitrogen was quantitatively determined by the distillation method described on pages 298-299. Organic nitrogen was measured by the Kjeldahl method using mercuric sulfate as a catalyst. This procedure is described on pages 305-307.

Nitrate and Nitrite Nitrogen

Nitrogen in the form of nitrates was determined by the phenol-disulfonic acid method described on pages 302-303. The nitrites, if present, were oxidized to nitrates with hydrogen peroxide in acid medium. This was the procedure used on the first five cruises of Lake Michigan. This method was run in duplicate with the Greis method for the Technicon Auto-Analyzer, described below, for analyses of 96 samples from the sixth cruise. The results obtained by the Greis method proved superior and the procedure was adopted for subsequent analyses.

Method for Nitrate Nitrogen by the Auto-Analyzer

Nitrogen in the form of nitrates was determined by the Greis Method following its reduction to nitrite, utilizing the Technicon Auto-Analyzer. The nitrates were reduced by means of a zinc column in an acid medium. The following procedure was followed:

1. Apparatus used:

   Technicon Auto-Analyzer. (20)

2. Reagents used:

   a. Sodium Acetate Solution: 34 g. per liter.

   b. Sodium Acetate Hydrochloric Acid Buffer Solution: 100 ml of hydrochloric acid (1 : 99) mixed with 1,000 ml of sodium acetate solution (a).

   c. Sulfanilic Acid Solution: 6.0 g. of sulfanilic acid plus 200 ml of concentrated hydrochloric acid per liter.

   d. Naphthylamine Hydrochloride Solution 6.0 g. of 1-naphthylamine hydrochloride, 10 ml of concentrated hydrochloric acid and 500 ml of 95 percent ethyl alcohol per liter. (This reagent

eventually becomes slightly discolored and may form a slight precipitate. If discoloration occurred it was removed by mixing with nitrate free activated carbon and filtering.)

e. Color Reagent: Equal volumes of sulfanilic acid reagent (c) and naphthylamine hydrochloride reagent (d) were mixed and stored in the dark for increased stability.

f. Zinc metal 30 mesh, granular, reagent grade. This zinc was washed with chloroform just before use.

g. Stock Nitrate Solution: 7.2138 g. of anhydrous potassium nitrate per liter. This solution contained 1 mg of nitrate nitrogen per ml.

h. A series of working standards from 0.05 to 3.0 mg per liter of nitrate nitrogen was prepared from the stock solution (g).

3. Procedure:

a. The analytical system was set up in accordance with the flow diagram provided by Technicon.

b. The instrument was standardized using standard solutions listed in 2 h. A distilled water wash was interposed between each standard.

c. Samples were arranged on the analyzer with a distilled water wash between each sample. A series of standards was introduced after each 10 samples to detect possible drift in the instrumentation.

d. Standardization curves were prepared which show the relationship of recorder response to concentration of nitrate as nitrogen. Sample results were evaluated by reference to this curve.

The precision of this method was compared with the Standard Method by analyzing 96 separate samples by both methods. The results were found to be in good agreement. This method was therefore adopted as a routine procedure because of its great superiority with respect to speed of analysis as well as improved precision.

Total Soluble Phosphate

This test was performed in accordance with procedures described in Standard Methods, Method C, Total Phosphate and Polyphosphate, pages 204-206, on samples filtered to remove suspended matter.

Silica

The procedure for silica was the Colorimetric Heteropoly Blue Method described on pages 228-229.

Dissolved Oxygen*

This test was performed in accordance with the procedure described as Method A, Alsterberg (Azide) Modification of the Winkler Method, pages 309-311.

Phenols

Phenols were determined as described on pages 404-408, using the Aminoantipyrene Method.

Methylene Blue Active Substances (MBAS)

The methylene blue procedure for determining MBAS, as described in Standard Methods, pages 245-251, was modified by this laboratory. The changes in no way affected the reproducibility of the method, but did speed up the procedure and economize on the use of time and reagents.

The modifications were as follows:

(a) The washing of extracts with wash solution was eliminated because comparative studies showed that values were equally reproducible and accurate without this step.

(b) Twenty-five ml aliquots or aliquots diluted to 25 ml were used for the analysis.

(c) Five ml of methylene blue solution was added to each sample. An additional amount, if needed, would be indicated by the water phase becoming clear after extraction with chloroform.

(d) The sample was extracted two times with 10 ml portions of chloroform and filtered through a pledget of cotton in the tip of the separatory funnel. This filtered and removed moisture from the chloroform extract satisfactorily.

(e) The sample was collected, made up to volume and read in the spectrophotometer at a wave-length of 650 millimicrons.

Biochemical Oxygen Demand*

The procedure for biochemical oxygen demand was the same as described on pages 318-323 in Standard Methods.

Hydrogen Ion Concentration (pH)*

This test was performed by the Glass Electrode Method as described on page 194.

Dissolved Solids

Dissolved solids were measured by the method described on pages 326-330 of Standard Methods titled "Filtrable Residue."

Sodium and Potassium

Sodium and potassium content were measured by the Flame Photometric Method as described on pages 231-232.

Calcium

The method used was the EDTA Titrimetric Method as recommended in Standard Methods pages 67-68.

Conductance (Specific)*

This test was performed using a specific conductance meter and cell as described on pages 114-116.

Total Alkalinity

This test was performed using a mixed indicator, consisting of two parts methyl orange and one part methyl purple, as described on pages 45-47.

Magnesium

This test was performed by the Photometric Method as described in Standard Methods on pages 153-154.

Sulfate

The Turbidimetric Method was used as described on pages 241-242.

Chloride

Chloride content was measured by the Mercuric Nitrate Method described on pages 326-330.

Metals (Toxic)

A polarographic technique was used to analyze water for toxic metals. Metals in concentrations as low as 0.01 mg/l can be determined, and with the addition of the range extender and/or greater concentration of sample, lower levels may be detected.

The method has been demonstrated to be as accurate as, and definitely more time-saving than, the usual colorimetric procedures for these metals. The precision was in the range of ± 3 percent.

RESULTS OF ANALYSIS

Samples of Lake Michigan water were subjected to a large number of physical and chemical analyses. The substances showing appreciable variability and likely to provide the greatest threat to satisfactory water quality for intended uses were found to be ammonia nitrogen, total soluble phosphate, silica, dissolved oxygen, and phenol. Therefore, the results of analysis of these constituents will be discussed in detail.

Average values and ranges of the various constituents found in water are cited most frequently in this report. However, when large variations or abnormalities are evident, individual results will be discussed in order to provide a more comprehensive account of the water quality in the Lake Michigan Basin.

Deepwater Studies

The deepwater region of Lake Michigan is defined as that portion of the Lake greater than 10 miles from shore. This region constitutes the bulk of Lake Michigan waters, and because it is the least affected by various forms of pollution, it will be used as a base line of water quality in the Basin.

The deepwater region was sampled during a series of seven cruises which began in May 1962 and were discontinued in November 1963 (Table 1). The average chemical results for this region are presented in Tables 3 and 4. Variations by season and depth of ammonia nitrogen, total soluble phosphate, silica, dissolved oxygen, and percent saturation are shown in Table 5. Since more of the samples analyzed were in the southern portion of the Lake, average values tend to be weighed in favor of this region.

Ammonia nitrogen concentrations ranged from not detectable at the limits of the test (N.D.) to 0.[illegible] mg/l throughout the deepwater region. The maximum value was found at a depth of 75 meters about 12 miles from Sturgeon Bay. The average ammonia nitrogen concentration was 0.06 mg/l.

The geographical distribution of ammonia nitrogen within the Lake Michigan Basin is shown in Figure 1. The inshore and deepwater regions are separated by a line located approximately 10 miles from shore. It should be pointed out that this and similar figures present only average values within a given area (a 15' quadrangle) and are used only to represent variations in water quality and not exact concentrations of any particular constituent at a specified point.

Figure 1 shows that, for the most part, there is little variation in ammonia concentrations throughout the deepwater region. The

water leaving Lake Michigan at the Straits of Mackinac had an average ammonia concentration of 0.05 mg/l which is only 0.01 mg/l lower than the average for the entire deepwater region. Several deepwater quadrangles had ammonia nitrogen concentrations above 0.08 mg/l. However, these areas are scattered and do not appear to correspond to ammonia sources.

Ammonia nitrogen concentrations are compared by season and depth in Table 5. Little variation is apparent except that concentrations found in the summer months were slightly higher than in the spring and fall.

Total soluble phosphate concentration (Table 5) averaged 0.02 mg/l in deep water. A uniform distribution throughout this region is evident from Figure 2. The highest phosphate concentration was 0.14 mg/l, found within 12 miles of Grand Haven. All other phosphate concentrations were below 0.09 mg/l.

Silica concentrations averaged 2.7 mg/l throughout the deepwater region. The concentration at individual stations ranged from 0.6 to 5.5 mg/l. The highest silica concentrations were found in the central and northern regions of the Lake as shown in Figure 3. Lower concentrations were evident near the shoreline and in the vicinity of harbors. In general, these low silica concentrates were found in regions of high biological activity (23).

Variations in silica concentrations by season and depth are shown in Table 5. Silica concentrations in the spring were fairly uniform at all depths, which can be attributed to mixing during the spring turnover. During the summer and fall months silica concentrations increased with depth. This effect may be attributed to thermal stratification of the water and greater biological uptake of silica in the upper layers of water than in the hypolimnion.

The average dissolved oxygen concentrations measured in the deepwater region are listed in Table 3. The percent saturations these dissolved oxygen concentrations represent are also included. As expected, the percent oxygen saturation was found to average 6 to 7 percent less below 30 meters than in the top few meters of water. Oxygen depletion from other than natural causes was not evident in the deepwater region. Table 6 indicates the minimum and maximum values encountered.

Toxic metal analyses were performed on a number of samples from each region of the Lake. The frequency of occurrence of each metal is given in Table 4. All toxic metals but cadmium were detected at the limit of sensitivity of the test (0.005 mg/l). This level is within the limits set by the U. S. Public Health Service Drinking Water Standards (4).

Averages and ranges of the other chemical substances studied in the deepwater region appear in Table 2. These parameters, namely nitrate and organic nitrogen, sodium, potassium, dissolved solids, specific conductance, pH, alkalinity, calcium, magnesium, chloride, and sulfate, showed some variability, but were of little water quality significance at the levels encountered.

Inshore Studies

Inshore areas of Lake Michigan were sampled during a series of eight cruises (Table 1) from August 1962 to October 1963. Samples were collected at one, four, seven and ten miles from shore at several depths, except in harbors. In addition to the parameters which were found significant in the deepwater studies, phenols were found in significant quantities in some of the inshore samples. The average chemical results and ranges are tabulated in Table 3. A comparison with the deepwater results shows higher average values and greater variations in all parameters analyzed in the inshore region.

Ammonia nitrogen concentrations in the inshore region ranged from N.D. (none detected) to 1.4 mg/l with an average concentration of 0.13 mg/l, more than twice the average concentration found in the deepwater region. Figure 1 shows that the highest concentrations were found in the vicinity of Calumet, Milwaukee, Benton Harbor, Saugatuck, Grand Haven, and Muskegon. Concentrations up to 1.4 mg/l were found near Calumet and 1.3 mg/l near Milwaukee Harbor.

Since almost half of the samples analyzed in the inshore region were taken in the vicinities of Calumet and Milwaukee, the average concentrations are heavily weighted by these two areas. However, excluding these areas, the average concentration becomes 0.10 mg/l, which is still substantially higher than found in deep water.

Total soluble phosphate concentrations in the inshore region are shown in Figure 2. Very high concentrations of soluble phosphates are found in the Milwaukee area. In quadrangles B-13, B-14 and C-14, the average concentrations were 0.10, 0.26, and 0.23 mg/l, respectively. In the same order, maximum concentrations were 3.1, 3.4, and 4.5 mg/l. These values indicate phosphate-rich water moving southward from Milwaukee Harbor.

Near the Calumet area, maximum phosphate concentrations of 0.45 mg/l were found in quadrangles D-19 and E-19. The average concentrations in these areas were 0.05 and 0.04 mg/l, respectively.

Aside from these two areas, the rest of the inshore region averaged less than 0.03 mg/l total soluble phosphate, which is only 0.01 mg/l higher than the deepwater region.

Silica concentrations found in the inshore region are shown in Figure 3. The average silica concentration of 1.7 mg/l is about half that found in the deepwater region indicating possibly greater biological uptake of the silica in the inshore region. The areas of low silica concentrations have been found to correspond to regions of high phytoplankton populations (23).

Water samples from a number of inshore stations were analyzed for phenolic materials. By far the highest concentrations were found in the vicinities of Indiana and Calumet Harbors. The maximum value in quadrangle D-19 was 72 micrograms per liter, while the average value was 3 micrograms per liter. In quadrangle C-19, the maximum concentration was 32 micrograms per liter. In contrast, the next highest phenol concentration in another quadrangle was 8 micrograms per liter found near Michigan City. In the Milwaukee area, phenols ran as high as 7 micrograms per liter and averaged 2 micrograms per liter.

Some phenolic pollution is evident between Muskegon and Kalamazoo where phenol concentrations up to 8 micrograms per liter were found. However, phenols were not detected in many samples from this area.

Chlorides were found in significant quantities near Ludington and Manistee. In quadrangles H-10, 9, and 8, maximum values 69, 94, and 77 mg/l, respectively, were found. The average values for these quadrangles were 14, 29, and 18 mg/l, respectively, while the overall average inshore chloride concentration was 7.1 mg/l. The major contributors of chlorides in the area are the Morton and Manistee Salt Companies which discharge near the mouth of the Manistee River up to 260,000 and 44,700 pounds of chloride per day, respectively.

The biochemical oxygen demand (BOD) was determined at a number of inshore stations. Outside the Milwaukee Harbor, maximum BODs of 6.7 mg/l were found in both quadrangles, B-13 and B-14. A BOD of 8.6 mg/l was found near the mouth of the Grand River on the eastern shore. In the inshore region adjacent to Gary, Indiana, BODs ranged up to 4.6 mg/l. These values indicate some degradation of the water quality when compared to the inshore average of 1.4 mg/l.

Averages and ranges of the other chemical parameters studied in the inshore region appear in Table 3. These parameters, namely nitrate and organic nitrogen, sodium, potassium, dissolved solids, specific conductance, pH, alkalinity, calcium, magnesium, and sulfate showed greater variability and higher average values than found in the deepwater region. Although the levels of these chemical substances encountered within the inshore region were not high enough to be considered critical for most water uses, they do indicate large amounts of pollutants being discharged into Lake Michigan daily and annually.

Major Lake Michigan Tributaries

A number of the major river systems entering into Lake Michigan were sampled weekly from March 1963 to April 1964. The streams Manistique, Manitowoc, Sheboygan, Milwaukee, Burns Ditch, St. Joseph, Kalamazoo, Grand, Muskegon, and Pere Marquette will be discussed in this section of this report. The tributaries to Green Bay will be discussed in subsequent sections, as will the Boardman River, Calumet River, and the Indiana Harbor Canal.

Sampling stations at each tributary were located as close to the river mouths as possible without becoming diluted with harbor or lake water. The principal objective of this tributary mouth sampling was to determine the loading of various substances carried by each river into Lake Michigan. Average chemical results and loadings are shown in Tables 7a and 7b.

Flows of each river were taken from U. S. Geological Survey flow records for the study period (25). Average flows at the gaging stations were corrected for the portion of drainage basin between the gaging station and the river's mouth.

Of all the chemical parameters measured for the tributaries, the two nutrients, total soluble phosphate and ammonia nitrogen, showed the most important variations. With respect to these two parameters, the influence of the tributaries on the water quality can be seen in Figures 1 and 2.

Except for the Fox River, which is discussed later under Green Bay, the greatest contributor of soluble phosphate to the Lake was found to be the Grand River, contributing 5,330 pounds per day. The St. Joseph River adds less than half this quantity, while Burns Ditch carries roughly 1,500 pounds of phosphate per day. Phosphate concentrations were found to be higher in the immediate vicinities of these river mouths, but the concentrations quickly dropped off moving out in the Lake. Although the Milwaukee River carries comparatively minor loads of phosphates, the Milwaukee area appears to have a major influence on the adjacent inshore waters with respect to phosphate. This influence is primarily a result of waste discharges from the Jones Island Sewage Treatment Plant, which contributes an estimated 6,600 pounds of total phosphates per day to the harbor.

The largest discharge of ammonia nitrogen to the Lake, with the exception of the Fox River, was found to originate from the Indiana Harbor Canal. Using an average flow of 1,500 cfs, the calculated daily discharge of ammonia nitrogen from the canal is 19,400 pounds. This massive load of ammonia nitrogen severely pollutes the adjacent inshore waters, where an average concentration of 0.18 mg/l was observed.

Of the other tributaries considered, the Grand and St. Joseph Rivers were found to be the largest contributors of ammonia nitrogen, with 7,000 and 5,900 pounds per day, respectively. The Kalamazoo River carried roughly half this amount while the Milwaukee and Muskegon Rivers contributed approximately a quarter as much at 1,600 per day. Inshore waters adjacent to these tributaries averaged 0.16 mg/l ammonia nitrogen.

Toxic metals were found in appreciable concentrations in the tributaries. Copper concentrations were usually highest, followed by nickel and zinc. Copper concentrations ranged from 0.06 mg/l to 0.15 mg/l. Although these values are well below the drinking water standard of 1.0 mg/l, concentrations as low as 0.02 mg/l have been reported harmful to aquatic life (3). Zinc concentrations were also well within the recommended limits for drinking water. Nickel concentrations were three times higher in the Sheboygan River than those in the other rivers studied. However, the levels of nickel encountered are not known to be a health hazard. On the other hand, cadmium concentrations in the St. Joseph River averaged 0.02 mg/l, which is twice the maximum limit recommended for drinking water. Furthermore, chromium concentrations of 0.04 mg/l, found in the Grand River, were very close to the limit of 0.05 mg/l (5). Such levels of toxic metals indicate serious impairment of water quality in the tributaries, especially in the Grand and St. Joseph Rivers.

For the most part, loadings of the other chemical constituents in each river appeared to correlate well with concentrations found in the inshore waters near the river mouths. These constituents may represent dissolved materials leached from the soil, municipal or industrial waste discharges, or urban and rural runoff. Dissolved solids and suspended solids loadings ranged from 58 to 1,790 tons per day and 7 to 23 tons per day, respectively. Aside from the nutrients and toxic metals, these materials have relatively little influence on the water quality of Lake Michigan.

Green Bay

The waters of Green Bay were sampled from June 26 to July 17, 1963. Figure 4 indicates the approximate locations of the stations sampled and the selected zones into which the bay has been divided to facilitate interpretation of the collected data. Each zone, except for tributary mouths, harbors, and nearshore areas, represents a region of similar water quality.

A summary of the physical and chemical findings is presented by zones in Table 8. Examination of this Table shows the following significant water quality effects:

1. A severe depletion of dissolved oxygen is evident in zone 1. Several samples with zero dissolved oxygen were found in this area. Some oxygen depletion is also evident near the Peshtigo River, in zone 3.

2. The average concentration of soluble phosphate in zone 1 is far above the level of 0.03 mg/l considered critical for the stimulation of algal blooms. In comparison, all the major harbors in Lake Michigan, except Milwaukee, had average concentrations less than half the value found in zone 1. Except for zone 5, soluble phosphate concentrations in the other zones in Green Bay were also at or above critical levels.

3. Ammonia nitrogen levels are by far the highest in zone 1. Throughout the other zones, concentrations are comparable or higher than those found in the inshore region of Lake Michigan.

4. Nitrate nitrogen concentrations are significantly low throughout the bay.

5. Phenol concentrations up to 40 micrograms per liter were found in zone 1. Higher concentrations within the Lake Michigan Basin were found only in Indiana Harbor.

6. The other parameters measured in Green Bay, such as chlorides, dissolved solids, and sulfates, also had much higher values in zone 1 than in the other regions of the bay, indicating a high volume of waste discharge and probably a lack of mixing in this area.

Green Bay joins Lake Michigan at zones 5 and 6. The water quality of these two zones is comparable with the average inshore water in Lake Michigan.

Green Bay Tributaries

The major tributaries into Green Bay were sampled weekly at the river mouths from June 1963 to May 1964. The physical and chemical findings obtained during this study are summarized in Tables 9a and 9b.

In order to illustrate the seriousness of waste discharges into Green Bay by the major tributaries, approximate average daily loadings of the two significant nutrients, ammonia nitrogen and phosphates, are compared in Figures 5 and 6, with the concentration of these constituents found in the Bay. Examination of these figures reveals the Fox River to be by far the most important contributor, discharging 6,670 pounds of total soluble phosphate daily, or three times the amount discharged by the Menominee, the next highest contributor of phosphate, and discharging 37,200 pounds of ammonia nitrogen, which is almost four times as much as the Oconto, the next highest ammonia nitrogen contributor at 9,840 pounds.

In fact, the Fox River adds more nutrients to Green Bay than all the other tributaries combined, which results in the high concentration found in zone 1.

The presence of toxic metals in detectable amounts can be considered a potential threat to continuing water uses. The other constituents measured in this study serve to differentiate the chemical water quality of the various streams. The composition of dissolved matter found may reflect the effects of minerals leached from the ground, municipal or industrial waste discharges, or urban drainage such as resulting from street salting for ice control. Except for the nutrients previously cited, these chemical inputs have relatively little influence on the chemical water quality of the Bay.

A special study consisting of intensive sampling of a stretch of the Fox River was conducted to determine the effect of organic wastes on stream oxygen resources. A typical profile of the dissolved oxygen and biochemical oxygen demand concentration found during this study are shown in Figure 7. The high BOD levels carried by the Lower Fox result in the complete absence of dissolved oxygen for a stretch of eleven miles and levels of less than 2 mg/l for over twenty miles. Fish and desirable aquatic life cannot survive under such degraded oxygen conditions. The odors and anaerobic gases released by this pollution make the stream esthetically undesirable and very objectionable for recreational uses. The organic loadings causing this highly polluted condition are known to originate primarily from the discharges of many pulp and paper mills located along the Lower Fox River and from domestic wastes.

Traverse Bay

Traverse Bay and the adjacent region of Lake Michigan (Figure 8) were sampled from July 22 to July 28, 1964. The average chemical results and the ranges encountered in this area are tabulated in Table 10.

The Boardman River is the only major tributary into Traverse Bay. This river was sampled weekly from April 4, 1963 to April 23, 1964. Samples were composited by flow prior to analysis. For comparative purposes, these results are also tabulated in Table 10.

In general, the west arm of Traverse Bay was found to contain higher concentrations of contaminants than the east arm. The Boardman River, which enters the west arm, and Traverse City, contribute to these higher values. The Boardman River influence is not large due to its low flow (255 cfs).

There appears to be no significant variation in general water quality between Traverse Bay and the adjacent inshore waters of the Lake.

Indiana Harbor

The Indiana Harbor receives drainage from the Grand Calumet River in northern Indiana as well as from a large industrial complex located along the harbor canal. Because of the large volume of waste discharge from these sources, considerable variation in water quality was observed between the Indiana Harbor and the adjacent inshore waters. The average chemical results and ranges encountered in this area are shown in Tables 11a and 11b.

The ammonia nitrogen concentrations in Indiana Harbor and Canal are presented in Figure 9. The highest values were observed in the Indiana Harbor Canal where concentrations up to 4.5 mg/l were found: the overall average in the Canal was 2.4 mg/l. In contrast, the highest concentration found in the Harbor was 2.3 mg/l. The average concentration in the Harbor was 1.4 mg/l, which is approximately eight times the average ammonia concentration (0.18 mg/l) in the adjacent inshore waters and 23 times that of the deepwater zone. Such high concentrations of ammonia indicate serious water quality degradation.

Seasonal variations of ammonia nitrogen concentrations appear in Table 15. Concentrations were found to increase substantially from spring to fall.

Total soluble phosphate concentrations showed little variation by station throughout the harbor, where average values ranged from 0.05 to 0.08 mg/l (Figure 10). In contrast with ammonia nitrogen values, phosphate concentrations were no higher in the Canal than in the Harbor. Seasonal variations of phosphates were not significant.

Phenol concentrations in the Harbor and Canal are presented graphically in Figure 11. Some of the highest phenol concentrations in the Lake Michigan Basin were found in the Indiana Harbor Canal, where concentrations as high as 354 micrograms per liter were found. Phenol concentrations averaged respectively 156 micrograms per liter in the Canal, 33 micrograms per liter in the Harbor, and 3 micrograms per liter in the adjacent inshore waters. This phenolic pollution has been found to be the major cause of frequent taste and odor problems in drinking water from as far north as the City of Chicago's South District Filtration Plant. Seasonal variation of phenol concentrations are shown in Table 18. Much lower concentrations were evident in the summer months than in the spring and fall.

The results of toxic metal analyses of Indiana Harbor water samples are shown in Table 11b. Only lead and zinc were found in detectable concentrations.

Dissolved oxygen concentrations in the Harbor averaged 2.7 mg/l. Concentrations varied from 0.4 to 10 mg/l, with corresponding saturation values ranging between 4.2 and 99 percent. Seasonal variations in dissolved oxygen were very pronounced. During the summer months the maximum saturation was only 39 percent, while in the spring saturations ranged up to 99 percent. Such values indicate massive loads of organic wastes within the Harbor.

Oil and grease averaged 4.4 mg/l in the Harbor, where concentrations ran as high as 29 mg/l. These values are quite high when compared to the Lake waters, where the concentration is practically nil, and emphasize the magnitude of industrial wastes discharged through the Harbor.

Calumet Harbor

Under normal conditions, the waters of Calumet Harbor move from the Lake toward the Calumet River due to diversion of water from the Lake. However, contamination of the Harbor from industrial and municipal wastes discharged into the Calumet River occurs during periods of heavy storms, when the usual direction of flow is reversed. The average chemical results and the ranges encountered during the study of Calumet Harbor are shown in Tables 11a and 11b.

Average ammonia nitrogen concentrations at the stations sampled are shown in Figure 9. Noting the scale differences in Figure 9, inspection shows that ammonia concentrations in the Calumet Harbor average less than one-quarter the concentration found in Indiana Harbor. However, the average concentration in the Calumet Harbor of 0.23 mg/l is still relatively high when compared to adjacent inshore average of 0.18 mg/l and the deep-water average of 0.06 mg/l. The seasonal variations in ammonia nitrogen concentrations are shown in Table 15. Maximum ammonia concentrations were found in the summer months.

Total soluble phosphate concentrations in Calumet Harbor are comparable with the levels found in Indiana Harbor (Figure 10). There were no significant seasonal variations in phosphate concentrations (Table 16).

Average phenol concentrations at the individual sampling stations are shown in Figure 11. Inspection of this figure reveals that all values were relatively low and did not vary significantly.

Dissolved oxygen concentrations averaged 8.5 mg/l, with a corresponding saturation of 90 percent. The minimum and maximum percent saturations in Table 17 indicate a slight seasonal variation, with the summer months showing the lower percent saturation.

As in Indiana Harbor, lead and zinc were the only toxic metals detected. Copper, cadmium, chromium, and nickel concentrations were all less than 0.005 mg/l - the sensitivity of the test. The average concentrations and ranges for toxic metals appear in Table 11b.

No significant variation was noted in the other parameters measured.

Chicago Harbor

The average chemical results for Chicago Harbor are shown in Tables 12 and 13. The geographical distribution of phosphate and ammonia nitrogen concentrations appear in Figures 12 and 13. Phenols were not detected in the Harbor. All parameters studied showed higher values in the southern end of the Harbor. However, in general, average results within the Harbor did not vary significantly from results of the adjacent inshore waters. Such results are expected since inshore waters normally flow through the Harbor toward the Chicago River, except during periods of heavy storms, when the flow may be reversed in a similar manner as the Calumet River, though less frequently.

Racine Harbor

The water quality of Racine Harbor is comparable to the Chicago Harbor, except for higher soluble phosphate and phenol concentrations.

Average ammonia nitrogen and phosphate concentrations at individual stations within the Harbor are shown in Figures 14 and 15, respectively. The range of phosphate concentrations for all stations is 0.07 to 0.10 mg/l, except for one station near the breakwall and one at the breakwall opening, where the concentrations were 0.03 and 0.01 mg/l, respectively. The adjacent inshore water had an average phosphate concentration of 0.03 mg/l.

Phenol concentrations are shown in Figure 16. A band of higher phenol concentrations was observed running north and south through the center of the Harbor. Concentrations at these stations ranged from 2 to 3 micrograms per liter, whereas all other stations showed levels of about 1.0. This may indicate a plume of phenolic pollution moving out from the mouth of the Root River, which drains into this Harbor, during the sampling period.

None of the other parameters measured showed significant differences between Racine Harbor and the adjacent inshore waters.

Milwaukee Harbor

Two studies of Milwaukee Harbor were made - one in the fall of 1962 and the second in the summer of 1963. Table 14 presents the number of samples, averages, and ranges for Milwaukee Harbor and waters adjacent to the Harbor.

Figures 17, 18, and 19 present sample station locations and concentration variations observed in each area for ammonia nitrogen, soluble phosphate, and phenol, three of the more critical water quality parameters.

In Figure 17, the highest ammonia nitrogen levels, 1.00-2.20 mg/l, are shown to be in the central area of the Harbor and in the Milwaukee River. These concentrations extended about one mile north of the mouth of the Milwaukee River and approximately three miles south along the shoreline.

Levels of 0.50-0.99 mg/l were found in the southeastern portion of the Harbor and in the northwestern side of the Harbor. The very northern section had concentrations of 0.15-0.49 mg/l. Waters adjacent to the breakwater from the center opening to the southern end, and with bands extending out into the Lake, had levels ranging from 0.15 to 0.49 mg/l. North of the breakwall along the shoreline, an area outside the Harbor and near the center of the breakwater, and an area south of the Harbor were 0.05-0.14 mg/l. All of the remaining waters adjacent to the Harbor had concentrations of N.D.-0.05 mg/l, which is typical of the background levels found in the lake proper.

As shown in Figure 18, the soluble phosphate values form a similar pattern to that of ammonia nitrogen. Concentrations of 0.49-1.3 mg/l extended generally from about one mile north of the river mouth to the southern end of the Harbor. A section in the southeast portion had levels of 0.15-0.49 mg/l. In the northwestern area of the Harbor, the concentrations were 0.15-0.49, and in the northeastern section 0.03-0.14 mg/l.

As stated previously, the major sources of phosphate within the area are the Milwaukee River, its tributaries, and the Jones Island Sewage Treatment Plant. The combined discharge from these sources has been estimated at 9,300 pounds of total phosphate per day (24).

In waters adjacent to the Harbor at the southern end of the breakwater, levels were observed ranging from 0.49-1.3 mg/l. A band extending along the entire length of the Harbor with tongues extending out into the Lake had concentrations of 0.03-0.14 mg/l. In all of the remaining waters adjacent to the Harbor the levels ranged from N.D.-0.03 mg/l, which is the level found throughout the Lake where no local inputs exist.

Figure 19 presents the phenol concentrations observed in Milwaukee Harbor and the adjacent waters of Lake Michigan. The phenol levels ranged from 5 to 8 micrograms per liter at the mouth of the Milwaukee River and for one mile north along the western side of the Harbor, in the very northern end, and on the southeastern side of the Harbor. Levels of 3-4 micrograms per liter were observed in a large area extending from the eastern side of the Harbor one mile north of the river to three miles south along the western side. A band in the adjacent waters extending from the north to the south along the shorelines and the breakwater had phenol concentrations of 1-2 micrograms per liter. Opposite the center opening in the breakwater, a band extended out into the Lake with concentrations of 3.0 micrograms per liter. Phenols were not detected in the remainder of the adjacent waters of Lake Michigan.

The other parameters listed in Table 14, except for dissolved oxygen, are higher in concentration than in the adjacent Lake waters. These high levels of chemical pollutants appeared to move into the Lake primarily from the southern end of the Harbor, as did ammonia nitrogen, phosphates, and phenols.

Evidence for substantial building-up of organic wastes within the Harbor is further provided by the depressed levels of dissolved oxygen encountered.

These gross indicators of chemical pollution are the result of effluent discharges from the Milwaukee Metropolitan Sewage District's Jones Island Treatment Plant, which services a domestic and industrial waste discharge of over two million population equivalents, plus the overflow during storms from combined sewers also serving this large population.

SUMMARY

Studies of chemical water quality were undertaken throughout Lake Michigan and environs. Of the chemical parameters considered, ammonia nitrogen, nitrate nitrogen, total soluble phosphate, dissolved oxygen, silica, toxic metals, and phenols were found to be significant in assessing variations in water quality. Although analyses were also conducted for organic nitrogen, sodium, potassium, dissolved solids, specific conductance, pH, alkalinity, calcium, magnesium, chloride, and sulfate, these substances were not considered to be of critical importance in the levels encountered.

Deepwater Studies

The deepwater studies provided a base line of water quality within the Lake Michigan watershed. Considerable uniformity was displayed throughout the deepwater region for most of the parameters measured. Lower silica concentrations found in surface samples during the summer months are believed to be due to uptake by plankton. There was little evidence of water quality deterioration within the deepwater region.

Inshore Studies

In contrast to the deepwater area, the inshore region of Lake Michigan was characterized by higher concentrations of dissolved substances and much greater variability in the parameters measured. In general, the largest variations were evident in the vicinity of localized inputs such as harbors and tributary mouths. The highest ammonia nitrogen concentrations were found just outside Indiana Harbor. The highest soluble phosphate concentrations, by far, were localized to the southeast of Milwaukee Harbor. Phenols, resulting from industrial pollution, were found in significant quantities in the vicinity of many tributaries and harbors. Major phenolic pollution was evident near Indiana Harbor. Within the inshore region, areas showing the greatest degradation in water quality were found in the vicinities of Indiana Harbor, Milwaukee Harbor, Benton Harbor, Grand Haven, and Saugatuck.

Major Tributaries

The major tributaries discharging directly to Lake Michigan were sampled at the river mouths over a period of one year. Loadings of numerous chemical substances carried by these rivers were calculated and appeared to correlate well with findings in the adjacent inshore waters.

Green Bay

Areas of degraded water quality were found in Green Bay. Serious pollution problems were especially evident in the southern end of the bay, near the mouth of the Fox River. These problems were due primarily to high concentrations of ammonia nitrogen, soluble phosphate, and phenol, and low dissolved oxygen concentrations resulting from organic wastes. Lack of mixing with other portions of the bay and large volumes of waste discharged intensify degradation of the waters in the southern end of the bay.

Green Bay Tributaries

Of the major tributaries discharging directly into Green Bay, the Fox River exhibited the most degraded water quality. This river was found to carry more nutrients into Green Bay than all the other tributaries combined. Massive amounts of organic contaminants discharged by municipalities and the many pulp and paper industries into the river helped produce, at times, little or no dissolved oxygen for distances exceeding 20 miles. The gross pollution evident in this river has been found to have a pronounced influence on the southern reaches of Green Bay.

The other tributaries to Green Bay were not as seriously degraded as the Fox River, but some evidence of industrial and municipal pollution was still apparent, especially in the Oconto and Menominee Rivers, which carried the next highest loads of ammonia nitrogen and soluble phosphates, respectively.

Traverse Bay

High concentrations of ammonia nitrogen and soluble phosphate were observed at the mouth of the Boardman River, resulting from the discharge of municipal and industrial wastes. The Boardman River enters the west arm of Traverse Bay causing slightly elevated levels of ammonia nitrogen and soluble phosphate in the western arm. Otherwise, there appears to be no significant variation in general water quality between Traverse Bay and the adjacent inshore waters of the Lake.

Harbors

Discharges of municipal and industrial wastes through the major harbors on Lake Michigan have a noticeable detrimental influence on the neighboring inshore waters. Indiana Harbor was found to be the most seriously polluted and showed the greatest degrading influence on the adjacent inshore waters of Lake Michigan. Some of the highest phenol and ammonia nitrogen concentrations in the Lake Michigan Basin were found in

the harbor and the adjoining canal. The high concentrations of dissolved substances, such as chlorides and sulfates, detected in this area indicate massive industrial pollution. Low concentrations of dissolved oxygen, evident during the summer months, underline the seriousness of organic contamination.

Studies of the water of Calumet Harbor indicated some water quality degradation, but at a lower level than found in Indiana Harbor. Under normal conditions, lake water passes through the harbor and down the Little Calumet River so that little contaminated water enters the harbor. However, during periods of heavy rainfall the flow can reverse and overflow from combined sewers and industrial waste discharges pass through the harbor into the Lake. Such a reversal can result in serious contamination of the adjoining Lake water.

The Chicago Harbor studies showed no significant differences between the harbor and adjacent inshore waters indicating no major pollution sources within the immediate area. However, since these values are higher than those found in the deepwater region (the base line within the watershed), contamination of this inshore region is evident, especially from the Calumet-Indiana Harbor area.

Studies of the Racine Harbor waters showed no significant differences between the harbor and adjacent inshore waters, indicating no major pollution source within the immediate area. However, phenols were observed in the harbor, indicating a source of industrial pollution. The inshore and harbor values are higher than those found in the deepwater region. Contamination of this inshore region can be attributed to the discharges of municipal and industrial wastes.

Milwaukee Harbor was found to be seriously polluted, second to Indiana Harbor, and showed a serious influence on the adjacent waters in this region. Some of the highest ammonia nitrogen and soluble phosphate concentrations in the Lake Michigan Basin were found in this harbor. The high concentrations of dissolved substances, such as chlorides and sulfates, detected in this area indicate massive municipal and industrial pollution. Low concentrations of dissolved oxygen and high biochemical oxygen demand underline the seriousness of organic contamination.

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TABLE 1

LAKE MICHIGAN SAMPLING CRUISES

EXTENDED RANGE

Cruise No.	Vessel	Inclusive Dates	No. of Stations	Area Sampled
1	M/V Cisco	4/24/62-5/7/62	36	Entire lake below Frankfort, Michigan.
2	M/V Cisco	6/5/62-6/18/62	29	Northern section and Green Bay.
3	M/V Cisco	7/17/62-7/30/62	31	Entire portion of lake below Ludington, Michigan.
8	M/V Kaho	11/28/62-12/6/62	22	Central portion of southern basin.
11	M/V Cisco	5/23/63-6/3/63	49	East shore from Saugatuck to Mackinaw City, Michigan. West shore from Upper Peninsula to Sturgeon Bay, Wisconsin.
16	T-509	7/15/63-7/26/63	22	Northern section of lake.
19	T-509	10/15/63-11/7/63	54	Southern half to Milwaukee-Muskegon line.
		INSHORE AND HARBOR		
4	M/V Cisco	8/29/62-9/9/62	70	Southwest shore - Gary, Ind. to Milwaukee, Wisc.
5	M/V Cisco	10/10/62-10/22/62	65	Southeast shore - Michigan City, Ind. to Muskegon, Mich.
6	R/V Fitzgerald	10/18/62-11/30/62	195	Chicago, Racine & Milwaukee Harbors and

TABLE 1 (Continued)

LAKE MICHIGAN SAMPLING CRUISES

INSHORE AND HARBOR (Continued)

Cruise No.	Vessel	Inclusive Dates	No. of Stations	Area Sampled
6 (Cont'd)				southwest shore from Gary, Ind. to Milwaukee, Wisc.
7	M/V Kaho	10/24/62-11/7/62	26	Southwest shore - Chicago, Ill. to Milwaukee, Wisc.
10	T-509	5/8/62-5/23/63	70	Calumet & Indiana Harbors.
11	M/V Cisco	5/23/63-6/3/63	49	East shore from Saugatuck to Mackinaw City, Michigan. West shore from Upper Penninsula to Sturgeon Bay, Wisc.
12	T-509	5/24/63-6/9/63	110	Southwest shore - Michigan City, Ind. to Milwaukee, Wisc.
13	T-509	6/9/63-6/13/63	41	Milwaukee Harbor.
14	T-509	6/13/63-6/25/63	110	Northwest shore - Milwaukee, Wisc. to Sturgeon Bay, Wisc
15	T-509	6/26/63-7/17/63	115	Green Bay, Escanaba and Menominee Harbors and all of Green Bay.
17	T-509	8/8/63-8/12/63 & 9/23/63-10/8/63	114	Eastern shore from Frankfort, Mich. to Michigan City, Ind.
18	T-509	8/20/63-9/12/63	50	Calumet, Ind., Gary, Burns Ditch Harbors.

TABLE 1 (Continued)

LAKE MICHIGAN SAMPLING CRUISES

INSHORE AND HARBOR (Continued)

Cruise No.	Vessel	Inclusive Dates	No. of Stations	Area Sampled
20*	T-509	10/20/63-12/8/63	42	Calumet, Indiana, Gary, and Burns Ditch Harbors.
22	T-509	7/22/64-7/28/64	42	Traverse Bay

*This cruise was designed primarily for tracing phenols. Only ammonia nitrogen, oil, and phenol samples were taken.

TABLE 2

MINIMUM DETECTABLE CONCENTRATIONS*
OF PHYSICAL AND CHEMICAL PARAMETERS MEASURED
IN THE LAKE MICHIGAN BASIN, 1962-1964

Parameter	Min. Det. Conc.	Parameter	Min. Det. Conc.
Acidity	2.0	Nitrogen	
		Nitrate	0.01
Alkalinity	2.0	Nitrite	0.01
Aluminum	0.02	Oil and Grease	0.2
Calcium	1.0	pH (pH units)	0.05
Chloride	0.5	Phenols (micrograms per liter)	1
Chlorine Demand	0.04		
		Potassium	0.10
COD (0.025N $K_2Cr_2O_7$)	2.0		
		Silica	0.02
Cyanide	0.02		
		Sodium	0.10
DO	0.1		
		Solids	1.0
Iron	0.02		
		Spec. Cond. (micromhos per centimeter)	0.5
Manganese	0.01		
Magnesium	1.0	Sulfate	1.0
MBAS	0.05	Sulfide	0.01
Nitrogen		Total Soluble Phosphate	0.01
Ammonia:			
Sodium Phenate	0.01	Toxic Metals	
Nesslerized	0.02	Rivers and Wastes	0.01
Titrated	0.10	Lakes	0.005
Conc. & Ness.	0.002		
Total Kjeldahl			
Nesslerization	0.02		
Titrated	0.10		
Conc. & Ness.	0.02		

*Concentration expressed as mg/l unless otherwise stated.

TABLE 3

CHEMICAL RESULTS OF PARAMETERS MEASURED IN
LAKE MICHIGAN BASIN IN 1962-1963
AVERAGES, RANGES, AND NUMBER OF SAMPLES

Parameter	Deepwater			Inshore		
	No. of Samples	Average (mg/l)	Range (mg/l)	No. of Samples	Average (mg/l)	Range (mg/l)
DO	1,080	12	8.4-17	2,541	10	3.7-16
Percent Saturation	497	102	73-152	1,701	102	43-148
BOD	NS*	-	-	730	1.4	ND-8.6
NH_3-N	429	0.06	ND-0.50**	1,751	0.13	ND-1.4
NO_3-N	595	0.13	ND-0.65	1,654	0.14	ND-0.90
Organic-N	313	0.19	ND-0.52	529	0.21	0.01-0.70
Total Sol. PO_4	388	0.02	ND-0.14	1,382	0.04	ND-5.0
SiO_2	299	2.5	0.6-5.5	645	1.7	0.4-4.4
Na	321	3.9	2.7-6.5	400	4.0	1.8-7.5
K	325	1.1	0.4-2.0	453	1.2	0.5-3.8
Dissolved Solids	417	155	100-240	976	175	86-810
Spec. Cond. (micro-mhos per centimeter)	918	260	185-345	2,452	285	33-1130
pH (pH units)	1,040		7.5-8.9	2,113		6.4-9.3
Alkalinity	858	110	75-130	2,169	105	70-210
Ca	395	33	25-40	616	35	17-40
Mg	318	12	8-16	898	12	7-14
Cl	607	6.5	3.3-11	1,611	7.1	1.5-94
SO_4	561	20	12-30	1,547	20	10-76
Phenols (micrograms per liter)	NS	-	-	1,033	2	ND-32

*NS = Not sampled.
**ND = Not detectable at sensitivity of test.
See Table 2.

TABLE 4

CHEMICAL RESULTS OF TOXIC METALS
LAKE MICHIGAN BASIN, 1962-1963
AVERAGES, RANGES, AND NUMBER OF SAMPLES

Metal	Deepwater		
	No. of Samples	Average (mg/l)	Range (mg/l)
Copper	58	<0.005*	
	3	0.010	0.007-0.012
Cadmium	61	<0.005	
Chromium	57	<0.005	
	3	.006	0.005-0.008
Nickel	33	<0.005	
	28	0.005	0.005-0.007
Zinc	48	<0.005	
	13	0.013	0.008-0.020

*0.005 mg/l limit of detection when using 1000 ml sample.

TABLE 5

VARIATIONS OF SELECTED CHEMICAL CONSTITUENTS
BY SEASONS, DEPTH, AND AVERAGES
LAKE MICHIGAN BASIN, 1962-1963

Parameters	Season	Depth (Meters) 0-5	6-10	11-30	31+
DO	Spring	13*	13	13	13
	Summer	11	11	13	13
	Fall	11	11	10	12
Percent Saturation	Spring	115	105	104	103
	Summer	107	109	112	103
	Fall	98	98	96	93
NH_3-N	Spring	0.05	0.04	0.07	0.05
	Summer	0.08	0.08	0.09	0.09
	Fall	0.06	NS**	0.06	0.06
Total Sol. PO_4	Spring	0.02	0.01	0.02	0.02
	Summer	0.02	0.01	0.02	0.02
	Fall	0.03	0.03	0.02	0.03
SiO_2	Spring	2.9	2.7	2.4	2.8
	Summer	1.6	1.6	2.3	4.5
	Fall	1.8	NS	1.9	2.2

*Concentration expressed in mg/l.
**NS - not sampled.

TABLE 6

DISSOLVED OXYGEN AND PERCENT SATURATION
IN DEEPWATER BY SEASONS
LAKE MICHIGAN BASIN, 1962-1963

Season	Depth	DO* (mg/l)		Percent Saturation	
		Minimum	Maximum	Minimum	Maximum
Spring	0-5	9.8	17	96	152
	6-10	7.1	14	100	110
	11-30	8.5	14	89	109
	31+	11	15	94	115
Summer	0-5	8.6	12	98	115
	6-10	9.4	14	103	119
	11-30	9.0	15	88	128
	31+	11	14	87	108
Fall	0-5	9.0	12	89	112
	6-10	9.0	12	93	102
	11-30	8.2	12	77	104
	31+	8.3	13	73	100

TABLE 7a

CHEMICAL RESULTS[1]
LAKE MICHIGAN TRIBUTARIES
AVERAGES, RANGES, AND LOADINGS

River		NH_3-N	NO_3-N	Org-N	Total Soluble PO_4	SiO_2	Total Dissolved Solids	Total Suspended Solids	Ca	Cl	SO_4
Manistique[3]	a	0.21	0.26	0.19	0.04	5.8	170	9.1	29	3.3	26
(845 cfs)	b	31	31	31	31	31	27	31	31	31	31
	c	0.08-0.66	0.08-1.8	0.02-0.56	0.02-0.09	2.4-7.6	52-190	3-19	16-32	1.6-5.5	1.2-43
	d	957	1180	865	182	26,400	774,000	41,500	132,000	15,000	118,000
Manitowoc[3]	a	0.38	0.31	0.40	0.62	5.7	260	29	42	12	36
(83 cfs)	b	41	41	41	41	41	35	41	41	41	41
	c	0.23-1.0	0.11-1.3	0.16-1.8	0.12-0.88	2.3-11	210-710	1-47	37-69	7.8-20	15-172
	d	170	139	179	277	2550	116,000	13,000	18,800	5360	16,100
Sheboygan[3]	a	0.63	0.87	0.69	0.40	3.9	310	26	50	21	48
(132 cfs)	b	32	29	32	41	39	39	41	39	39	39
	c	0.16-1.0	0.46-4.0	0.19-1.9	0.15-1.3	2.6-7.4	210-445	11-114	35-66	8.6-41	33-70
	d	448	619	491	285	2780	221,000	18,500	35,600	15,000	34,200
Milwaukee[3]	a	1.5	0.80	0.66	0.61	2.8	365	24	49	26	72
(191 cfs)	b	32	32	32	23	32	19	31	15	32	15
	c	0.94-3.4	0.25-2.1	0.06-1.9	0.27-1.1	1.5-6.0	230-560	11-73	43-63	19-40	41-163
	d	1545	824	680	628	2880	376,000	24,700	50,500	26,800	76,200
Burns Ditch[3]	a	1.4	0.72	0.89	1.8	10	445	21	84	38	87
(150 cfs)	b	36	36	36	36	38	36	36	40	40	40
	c	1.2-1.7	0.25-2.5	0.61-1.2	0.63-2.9	6.2-12	350-590	3-99	62-96	12-80	42-100
	d	1130	582	720	1456	8090	360,000	17,000	68,000	30,700	70,400

TABLE 7a (Continued)

CHEMICAL RESULTS[1]
LAKE MICHIGAN TRIBUTARIES
AVERAGES, RANGES, AND LOADINGS

River		NH_3-N	NO_3-N	Org-N	Total Soluble PO_4	SiO_2	Total Dissolved Solids	Total Suspended Solids	Ca	Cl	SO_4
St.Joseph[2]	a	0.53	0.59	0.53	0.24	6.4	310	21	62	16	59
(2060 cfs)	b	55	54	55	49	55	55	49	40	55	55
	c	0.02-0.94	0.11-2.1	0.07-2.4	0.05-0.94	1.3-15	240-355	5-55	55-70	12-18	50-75
	d	5890	6550	5890	2670	71,000	3,440,000	233,000	688,000	178,000	655,000
Kalamazoo[2]	a	0.46	0.58	0.80	0.21	5.9	360	20	71	34	70
(1140 cfs)	b	52	52	51	52	53	53	44	53	53	53
	c	0.05-0.84	0.10-2.3	0.33-1.3	0.03-0.68	2.3-9.6	200-470	2-39	55-80	14-109	14-84
	d	2830	3560	4920	1290	36,300	2,210,000	123,000	436,000	209,000	430,000
Grand[2]	a	0.68	0.72	0.77	0.52	5.3	350	24	72	42	74
(1900 cfs)	b	52	51	52	52	52	51	44	52	52	52
	c	0.05-1.5	0.04-2.4	0.15-1.5	0.12-1.1	2.5-17	275-570	6-84	51-85	19-67	56-100
	d	6970	7370	7890	5330	54,300	3,580,000	246,000	737,000	430,000	758,000
Muskegon[2]	a	0.17	0.24	0.33	0.06	5.6	235	10	30	21	24
(1731 cfs)	b	51	54	54	54	54	54	41	54	54	54
	c	0.01-0.36	0.15-0.95	0.11-1.0	0.01-0.21	3.6-8.1	185-280	4-25	22-51	17-29	15-48
	d	1590	2240	3080	560	52,300	2,190,000	93,000	280,000	196,000	224,000
Pere Marquette[2]	a	0.19	0.16	0.17	0.03	7.8	215	11	40	14	23
(570 cfs)	b	53	49	53	53	53	53	47	53	50	53
	c	ND[4]-0.33	0.06-0.48	0.03-0.84	0.01-0.07	5.7-10	135-255	4-23	23-43	6.0-16	15-32
	d	584	492	522	92	24,000	661,000	33,800	123,000	43,000	70,700

a - Average (mg/l).
b - Number of samples.
c - Range (mg/l).
d - Loading (lbs/day).

1-Composited samples according to flow, except all toxic metals represent a single composite.
2-March 1963 - April 1964.
3-June 1963 - April 1964.
4-ND-not detectable at the sensitivity of test, see Table 2.

TABLE 7b

CHEMICAL RESULTS[1]
LAKE MICHIGAN TRIBUTARIES
AVERAGES, RANGES, AND LOADINGS

River		Na	K	Mg	MBAS	Cu	Cd	Ni	Zn	Cr
Manistique[3]	a	2.1	0.8	7.6	0.18	0.08	ND[4]	0.02	0.02	ND
(845 cfs)	b	31	31	31	31	31	31	31	31	31
	c	1.1-3.2	0.6-1.0	3.3-9.9	0.08-0.08	NS	NS	NS	NS	NS
	d	9570	3640	34,600	820	364	-	91.0	91.0	-
Manitowoc[3]	a	11	3.1	18	0.09	0.11	ND	0.03	0.03	ND
(83 cfs)	b	41	41	41	34	41	41	41	41	41
	c	4.8-17	1.5-8.5	7.4-26	ND-0.20	0.11-0.11	-	0.03-0.03	0.03-0.03	-
	d	4920	1390	8050	40.2	49.2	-	13.4	13.4	-
Sheboygan[3]	a	17	3.2	24	0.18	0.09	ND	0.14	0.11	ND
(132 cfs)	b	39	39	39	39	39	39	39	39	39
	c	5.4-54	1.8-6.1	18-30	0.09-0.33	0.09-0.09	-	0.14-0.14	0.11-0.11	-
	d	12,100	2280	17,100	128	64.1	-	99.7	78.3	-
Milwaukee[3]	a	23	3.0	18	0.24	0.11	ND	0.04	0.06	ND
(191 cfs)	b	32	32	32	32	32	32	32	32	32
	c	14-49	2.2-4.8	15-28	0.11-0.41	0.11-0.11	-	0.04-0.04	0.06-0.06	-
	d	23,700	3090	69,000	247	113	-	41.2	61.8	-
Burns Ditch[3]	a	23	3.8	22	0.28	0.07	ND	0.03	ND	ND
(150 cfs)	b	40	40	38	40	40	40	40	40	40
	c	4.4-33	3.2-5.0	15-31	0.10-0.40	0.07-0.07	-	0.03-0.03	-	-
	d	18,600	3070	17,800	227	56.6	-	24.3	-	-

TABLE 7b (Continued)

CHEMICAL RESULTS[1]
LAKE MICHIGAN TRIBUTARIES
AVERAGES, RANGES, AND LOADINGS

River		Na	K	Mg	MBAS	Cu	Cd	Ni	Zn	Cr
St.Joseph[2]	a	9.2	1.9	21	0.12	0.08	0.02	0.01	0.03	ND
(2060 cfs)	b	55	55	55	55	55	55	55	55	55
	c	5.4-11	1.5-2.3	14-25	0.09-0.18	0.08-0.08	0.02-0.02	0.01-0.01	0.03-0.03	-
	d	102,000	21,100	233,000	1330	888	222	111	333	-
Kalamazoo[2]	a	22	2.1	22	0.14	0.07	ND	0.03	ND	ND
(1140 cfs)	b	53	53	53	53	53	53	53	53	53
	c	7.5-32	1.7-2.8	9.4-28	0.08-0.22	0.07-0.07	-	0.03-0.03	-	-
	d	135,000	12,900	135,000	860	430	-	184	-	-
Grand[2]	a	28	2.8	26	0.28	0.14	ND	0.04	ND	0.04
(1900 cfs)	b	52	52	52	52	52	52	52	52	52
	c	7.1-43	2.1-3.9	16-30	0.11-0.73	0.14-0.14	-	0.04-0.04	-	0.04-0.04
	d	287,000	28,700	266,000	2870	1440	-	410	-	410
Muskegon[2]	a	9.4	1.1	14	0.12	0.11	ND	0.03	ND	ND
(1731 cfs)	b	54	54	54	54	54	54	54	54	54
	c	6.3-13	1.0-1.5	10-18	0.06-0.23	0.11-0.11	-	0.03-0.03	-	-
	d	87,700	10,300	131,000	1120	1030	-	280	-	-
Pere	a	9.8	0.8	14	0.08	0.12	ND	0.05	0.03	ND
Marquette[2]	b	53	53	53	53	53	53	53	53	53
(570 cfs)	c	5.4-36	0.7-1.1	7.6-17	0.04-0.14	0.12-0.12	-	0.05-0.05	0.03-0.03	-
	d	30,100	2460	43,000	246	369	-	154	92.2	-

TABLE 7b (Continued)

CHEMICAL RESULTS[1]
LAKE MICHIGAN TRIBUTARIES
AVERAGES, RANGES, AND LOADINGS

River	Na	K	Mg	MBAS	Cu	Cd	Ni	Zn	Cr

a - Average (mg/l).
b - Number of samples.
c - Range (mg/l).
d - Loading (lbs/day).

1 - Composited samples according to flow, except all toxic metals represent a single composite.
2 - March 1963 - April 1964.
3 - June 1963 - April 1964.
4 - Not detectable at sensitivity of test. See Table 2.

TABLE 8

CHEMICAL RESULTS BY ZONES IN GREEN BAY
JUNE 26 - JULY 17, 1963
AVERAGES AND NUMBER OF SAMPLES

Zone	DO mg/l		Percent Saturation		NH_3-N	NO_3-N	Total Sol. PO_4	SiO_2	Dissolved Solids	Cl	SO_4	Phenol
	Avg.	Min.	Avg.	Min.	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	micrograms per liter
1	(7) 4.5	0.0	(7) 52	0	(17) 0.46	(3) 0.01	(19) 0.20	(19) 1.7	(10) 233	(11) 13	(11) 22	(3) 21
2	(17) 8.3	7.3	(17) 93	80	(21) 0.13	(17) 0.02	(21) 0.06	(19) 1.5	(14) 188	(17) 7.9	(17) 19	(4) 3
3	(12) 8.2	5.1	(12) 88	48	(13) 0.18	(9) 0.04	(10) 0.07	(9) 1.5	(6) 181	(11) 6.7	(9) 19	(9) 4
4	(20) 9.2	7.2	(20) 92	83	(19) 0.17	(21) 0.06	(20) 0.03	(20) 2.0	(10) 178	(14) 6.6	(14) 19	(7) ND
5	(27) 10.4	9.3	(27) 101	95	(27) 0.12	(27) 0.10	(3) 0.01	(25) 2.1	NS	(24) 6.5	(24) 17	(1) 3
6	(33) 10.8	9.8	(33) 108	101	(30) 0.13	(29) 0.10	(29) 0.05	(28) 2.4	(14) 175	(24) 6.6	(25) 20	(2) 2
7	(47) 9.9	7.7	(47) 104	79	(32) 0.17	(31) 0.08	(31) 0.07	(31) 2.3	(21) 173	(30) 5.9	(31) 19	(10) 3
8	(18) 10.0	9.2	(18) 103	92	(11) 0.13	(12) 0.05	(12) 0.09	(12) 2.4	(8) 165	(12) 6.3	(12) 19	(3) ND
Total Averages	10.0	-	100		0.17	0.08	0.07	2.1	183	7.0	19	3
Total No. of Samples	181		181		170	149	145	163	83	143	143	39
Range:	0.0-13		ND-121		0.01-1.2	ND-0.43	0.01-0.60	0.5-9.7	132-279	1.5-18	9.5-26	ND-40

( ) denotes number of samples.
NS denotes not sampled.
ND denotes not detectable at limits of test. See Table 2.

TABLE 9a

CHEMICAL RESULTS
GREEN BAY TRIBUTARIES 1963-1964
AVERAGES, RANGES, AND LOADINGS

River		NH_3-N	NO_3-N	Org-N	Total Soluble PO_4	SiO_2	Total Dissolved Solids	Total Suspended Solids	Ca	Cl	SO_4
Fox[2]	a	1.6	0.10	0.48	0.28	9.4	271	25	40	21	52
(4420 cfs)	b	18	18	18	18	18	13	18	18	18	18
	c	1.1-1.7	0.05-0.23	0.37-0.53	0.14-0.45	9.2-9.8	196-285	17-59	38-44	16-28	42-75
	d	37,200	2380	11,400	6670	224,000	6,460,000	596,000	953,000	500,000	1,240,000
Oconto[2]	a	2.3	0.20	0.92	0.17	9.2	262	14	39	15	22
(790 cfs)	b	42	40	42	42	42	42	42	42	42	42
	c	0.09-6.3	0.04-0.43	ND-8.4	0.03-0.50	7.0-10	196-342	8-29	33-43	5.8-20	8.5-66
	d	9840	852	3920	724	39,200	1,120,000	60,000	166,000	63,900	93,700
Peshtigo[2]	a	0.14	0.15	0.45	0.08	9.8	281	15	33	11	24
(890 cfs)	b	38	37	38	42	44	44	44	44	44	44
	c	0.06-0.30	0.02-0.50	0.20-1.1	0.01-0.23	1.6-17	132-1212	2-24	24-38	0.9-72	1.3-134
	d	672	720	2159	384	47,000	1,350,000	72,000	158,000	52,800	15,200
Menominee[3]	a	0.24	1.7	0.39	0.11	4.4	154	13	28	7.3	17
(3250 cfs)	b	18	18	18	15	18	14	15	18	18	18
	c	0.05-0.30	ND-2.6	0.09-0.55	0.02-0.15	4.0-6.4	45-187	4-32	22-29	4.0-9.0	6.5-23
	d	4200	29,300	6833	1930	77,100	2,700,000	228,000	491,000	128,000	299,000
Ford[2]	a	0.12	0.40	0.45	0.04	7.0	203	7.1	40	2.7	20
(337 cfs)	b	45	45	45	25	45	24	20	45	45	45
	c	0.02-0.35	0.01-1.5	0.13-0.84	ND-0.22	6.0-8.8	141-303	4.0-8.0	27-50	2.0-4.5	7.4-43
	d	218	727	818	73	12,700	369,000	12,900	72,700	4906	36,300

TABLE 9a (Continued)

CHEMICAL RESULTS
GREEN BAY TRIBUTARIES 1963-1964
AVERAGES, RANGES, AND LOADINGS

River		NH_3-N	NO_3-N	Org-N	Total Soluble PO_4	SiO_2	Total Dissolved Solids	Total Dissolved Solids	Ca	Cl	SO_4
Escanaba[2]	a	0.11	0.10	0.41	0.06	7.0	166	16	28	2.8	20
(1017 cfs)	b	42	42	42	38	44	44	44	44	44	44
	c	0.04-0.17	0.04-0.35	0.14-1.2	0.01-0.33	4.7-9.1	72-230	6-77	13-31	1.9-5.0	1.0-50
	d	60.3	548	2248	329	38,400	910,000	87,700	154,000	15,400	110,000
Rapid[3]	a	0.62	0.24	0.89	1.59	3.1	240	18	35	5.5	4.1
(80 cfs)	b	17	17	17	17	17	17	17	17	17	12
	c	0.04-0.94	ND-0.49	0.15-1.8	0.01-3.9	2.7-4.0	168-531	2-86	28-37	2.2-7.1	3.0-10
	d	267	103	384	686	1340	103,000	7760	15,100	2370	1770
White Fish[3]	a	0.11	0.14	0.25	0.18	5.7	196	5	34	2.0	20
	b	15	15	15	18	18	15	18	18	18	18
(227 cfs)	c	0.09-0.12	0.12-0.18	0.23-0.30	0.04-1.0	4.2-6.9	170-209	3-8	27-37	1.5-2.5	11-33
	d	135	171	306	220	6980	240,000	6120	41,600	2450	24,500

a - Average concentration (mg/l).
b - Number of samples.
c - Range (mg/l).
d - Loading (lbs/day).

1 - Composites prepared according to flow, except all toxic metals values represent a single composite.
2 - June 12, 1963 - May 6, 1964.
3 - June 12, 1963 - October 24, 1963.
4 - ND - Not detectable at sensitivity of test. See Table 2.

TABLE 9b

CHEMICAL RESULTS
GREEN BAY TRIBUTARIES 1963-1964
AVERAGES, RANGES, AND LOADINGS

River		Na	K	Mg	MBAS	Cu	Cd	Ni	Zn	Cr
Fox[2]	a	14	3.8	14	-	0.09	ND	0.02	ND	ND
(4420 cfs)	b	18	18	18	NS	18	18	18	18	18
	c	10-16	2.9-4.3	9.8-21	-	0.09-0.09	-	0.02-0.02	-	-
	d	334,000	91,000	334,000	-	2140	-	476	-	-
Oconto[2]	a	3.8	1.8	14	0.10	0.01	ND	0.03	0.03	ND
(790 cfs)	b	42	42	42	42	42	42	42	42	42
	c	2.6-4.4	1.2-3.9	9.2-16	0.01-0.14	0.01-0.01	-	0.03-0.03	0.03-0.03	-
	d	16,200	7670	60,000	426	42.6	-	128	128	-
Peshtigo[2]	a	2.5	1.3	12	0.12	0.15	ND	0.03	0.04	ND
(890 cfs)	b	44	44	44	44	44	44	44	44	44
	c	1.3-4.6	0.8-4.1	8.5-32	ND-1.6	0.15-0.15	-	0.03-0.03	0.04-0.04	-
	d	12,000	6240	57,600	576	720	-	144	192	-
Menominee[3]	a	2.7	1.2	11	0.09	-	-	-	-	-
(3250 cfs)	b	18	18	18	18	NS	NS	NS	NS	NS
	c	1.6-3.1	0.9-1.4	9.0-12	0.08-0.10	-	-	-	-	-
	d	47,300	21,000	19,300	1577	-	-	-	-	-
Ford[2]	a	1.8	1.1	20	0.18	0.06	ND	0.03	0.03	ND
(337 cfs)	b	45	45	45	45	45	45	45	45	45
	c	1.0-2.4	0.5-1.3	10-28	0.08-0.71	0.06-0.06	-	0.03-0.03	0.03-0.03	-
	d	3270	2000	36,300	327	109	-	54.5	54.5	-

TABLE 9b (Continued)

CHEMICAL RESULTS
GREEN BAY TRIBUTARIES 1963-1964
AVERAGES, RANGES, AND LOADINGS

River		Na	K	Mg	MBAS	Cu	Cd	Ni	Zn	Cr
Escanaba[2]	a	2.9	1.1	9.0	0.21	0.09	ND	0.03	0.03	ND
(1017 cfs)	b	44	44	44	44	44	44	44	44	44
	c	1.4-3.9	0.7-1.5	4.2-11	0.08-0.60	0.09-0.09	-	0.03-0.03	0.03-0.03	-
	d	15,900	6030	49,300	1151	493	-	164	164	-
Rapid[3]	a	1.8	1.5	12	0.14	-	-	-	-	-
(80 cfs)	b	17	17	17	17	NS	NS	NS	NS	NS
	c	0.7-2.4	0.4-2.2	8.0-14	0.09-0.17	-	-	-	-	-
	d	776	646	5170	60.3	-	-	-	-	-
White-fish[3]	a	3.4	0.7	14	0.10	-	-	-	-	-
	b	18	18	18	18	NS	NS	NS	NS	NS
(227 cfs)	c	2.4-4.5	0.5-0.9	9.7-15	0.08-0.16	-	-	-	-	-
	d	4160	85.7	17,100	122	-	-	-	-	-

a - Average concentration (mg/l).
b - Number of samples.
c - Range (mg/l).
d - Loading (lbs/day).

1 - From composites prepared according to flow, except all toxic metals values represent a single composite.
2 - June 12, 1963 - May 6, 1964.
3 - June 12, 1963 - October 24, 1963.

ND - not detectable at sensitivity of test. See Table 2.
NS - not sampled.

TABLE 10

CHEMICAL RESULTS
TRAVERSE BAY, BOARDMAN RIVER, AND ADJACENT
REGION OF LAKE MICHIGAN, JULY 22-JULY 28, 1964

Parameter	Boardman River*				Traverse Bay			Adjacent Region of Lake Michigan		
	No. of Samples	Average mg/l	Range mg/l	Loadings lbs/day	No. of Samples	Average mg/l	Range mg/l	No. of Samples	Average mg/l	Range mg/l
DO	NS	-	-	-	78	11	8.7-13	29	11	9.4-12
Percent Saturation	NS	-	-	-	78	106	101-108	29	107	100-112
BOD	NS	--	-	-	6	1.2	0.6-1.7	NS	-	-
NH_3-N	51	0.29	0.04-0.66	399	59	0.05	0.01-0.42	27	0.03	0.01-0.11
NO_3-N	51	0.44	0.21-1.5	606	59	0.16	0.06-0.40	29	0.16	0.10-0.26
Total Sol. PO_4	50	0.20	0.04-0.36	275	59	0.03	0.01-0.18	28	0.02	0.01-0.07
SiO_2	51	7.5	7.0-8.4	10,328	51	2.1	0.9-4.2	15	1.4	0.9-2.1
Na	51	4.5	3.9-5.2	6,197	51	3.9	2.8-4.8	15	4.2	3.9-4.6
K	51	0.8	0.7-1.0	1,101	51	1.2	1.0-1.6	15	1.2	1.0-1.3
Dis. Solids	51	222	180-275	305,694	34	190	105-745	11	175	150-250
Spec. Cond. (micromhos/cm)	NS	-	-	-	78	305	300-315	29	305	300-310
pH (pH units)	NS	-	-	-	78		7.9-8.8	26		7.9-8.5
Alkalinity	NS	-	-	-	78	115	110-130	29	115	110-125
Ca	51	47	45-51	64,719	72	35	26-43	29	35	30-38
Mg	51	13	9.8-14	17,901	51	12	11-13	15	12	12-13
Cl	51	6.7	3.0-9.2	9,226	51	7.2	5.5-13	15	6.7	6.0-7.5
SO_4	51	13	3.7-16	17,901	51	18	12-22	15	19	17-24
MBAS	40	0.07	0.0[illegible]-0.08	96	118	0.03	0.01-0.06	43	0.03	0.02-0.05

*Sampled from April 11, 1963 to April 15, 1964; samples composited by flow.
NS - not sampled.

TABLE 11a

CHEMICAL RESULTS
INDIANA AND CALUMET HARBORS
LAKE MICHIGAN BASIN, 1962-1963
AVERAGES, RANGES, AND NUMBER OF SAMPLES

Parameter	Indiana			Calumet		
	No. of Samples	Average mg/l	Range mg/l	No. of Samples	Average mg/l	Range mg/l
DO	30	2.7	0.4-10	32	8.5	6.8-10
Percent Saturation	22	29	4.2-99	32	90	77-98
BOD	12	3.5	1.9-5.1	15	1.3	1.0-2.1
NH_3-N	49	1.4	0.10-2.3	53	0.23	0.05-0.67
NO_3-N	21	0.16	0.01-0.84	16	0.12	0.01-0.35
Organic-N	2	0.72	0.65-0.78	2	0.49	0.48-0.50
Total Sol. PO_4	15	0.05	0.02-0.12	15	0.05	0.01-0.14
SiO_2	21	2.5	1.6-3.8	19	1.6	1.0-3.0
Na	21	10	7.4-16	20	4.9	4.1-6.1
K	20	2.6	1.8-3.8	20	1.6	1.1-2.0
Dis. Solids	14	225	195-265	15	195	165-230
Spec. Cond. (micromhos/cm)	24	355	245-500	30	285	240-325
pH (pH units)	26	-	6.0-7.8	24	-	6.4-8.4
Alkalinity	26	110	100-125	24	110	95-135
Ca	23	40	37-43	20	35	34-37
Mg	21	15	14-15	14	13	11-14
Cl	21	16	10-22	21	7.6	6.8-9.0
SO_4	21	47	38-69	18	24	22-25
Phenols (micrograms per liter)	39	33	2.4-127	52	2	ND-12
Phenols-Canal* (micrograms per liter)	12	159	43-354	NS	-	-
Oil and Grease	18	4.4	0.4-29	19	1.6	0.1-3.4

*Indiana Harbor Canal.
NS - not sampled.

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TABLE 11b

CHEMICAL RESULTS OF TOXIC METALS
INDIANA AND CALUMET HARBORS
LAKE MICHIGAN BASIN, 1962-1963
AVERAGES, RANGES, AND NUMBER OF SAMPLES

Metal	Indiana			Calumet		
	No. of Samples	Average mg/l	Range mg/l	No. of Samples	Average mg/l	Range mg/l
Copper	8	<0.005*		7	<0.005	
Cadmium	8	<0.005		7	<0.005	
Chromium	8	<0.005		7	<0.005	
Nickel	8	<0.005		7	<0.005	
Zinc	8	0.047	0.009-0.087	7	0.046	0.025-0.053

*0.005 mg/l limit of detection when using 1000 ml samples.

TABLE 12

CHEMICAL RESULTS
CHICAGO AND RACINE HARBORS
LAKE MICHIGAN BASIN, 1962-1963
AVERAGES, RANGES, AND NUMBER OF SAMPLES

Parameter	Chicago			Racine		
	No. of Samples	Average mg/l	Range mg/l	No. of Samples	Average mg/l	Range mg/l
DO	12	11	7.8-13	8	11	11-12
Percent Saturation	5	104	86-110	7	96	90-101
BOD	4	0.8	0.6-1.6	3	0.7	0-2.1
NH_3-N	7	0.07	0.02-0.16	7	0.06	0.05-0.08
NO_3-N	14	0.10	0.05-0.11	NS	-	-
Organic-N	6	0.20	0.09-0.32	6	0.29	0.17-0.36
Total Sol. PO_4	14	0.04	0.01-0.15	-	0.07	0.01-0.10
SiO_2	5	1.2	0.75-2.0	7	1.6	1.4-1.9
Dis. Solids	3	150	145-155	1	155	155-155
Spec. Cond. (micromhos/cm)	10	315	270-350	8	305	230-335
pH (pH units)	11	-	7.8-8.7	8	-	7.9-8.3
Alkalinity	10	100	70-120	10	110	110-112
Ca	6	32	31-33	7	34	33-34
Mg	6	11	10-12	7	11	10-12
Cl	6	7.1	6.6-7.9	7	8.5	6.8-9.1
SO_4	6	22	20-23	7	22	18-24
Phenols (micrograms per liter)	4	ND	-	7	2	1-3

NS - not sampled.
ND - not detectable at the sensitivity of test. See Table 2.

TABLE 13

CHEMICAL RESULTS OF TOXIC METALS
CHICAGO AND MILWAUKEE HARBORS
LAKE MICHIGAN BASIN, 1962-1963
AVERAGES, RANGES, AND NUMBER OF SAMPLES

Metal	Chicago			Milwaukee		
	No. of Samples	Average mg/l	Range mg/l	No. of Samples	Average mg/l	Range mg/l
Copper	1	<0.005*		6	<0.005	
Cadmium	1	<0.005		6	<0.005	
Chromium	1	<0.005		5	<0.005	
				1	0.005	0.005-0.005
Nickel	1	<0.005		3	<0.005	
				3	0.007	0.005-0.009
Zinc	1	<0.005		6	<0.005	

*0.005 mg/l limit of detection when using a 1000 ml sample.

TABLE 14

CHEMICAL RESULTS
MILWAUKEE HARBOR AND ADJACENT WATERS OF LAKE MICHIGAN
LAKE MICHIGAN BASIN, OCTOBER 1962-JUNE 1963
AVERAGES, RANGES, AND NUMBER OF SAMPLES

Parameter	Harbor			Water Adjacent to Harbor		
	No. of Samples	Average mg/l	Range mg/l	No. of Samples	Average mg/l	Range mg/l
DO	48	11	5.3-15	74	12	8.7-15
Percent Saturation	26	116	77-139	27	117	108-144
BOD	60	3.4	1.5-8.1	25	2.5	0.3-6.7
NH_3-N	35	1.1	0.28-2.7	74	0.18	ND-1.3
NO_3-N	35	0.15	0.04-0.24	81	0.14	0.03-0.90
Organic-N	14	0.37	0.30-0.67	46	0.27	0.01-0.58
Total Sol. PO_4	36	0.44	ND-1.4	67	0.07	ND-0.70
SiO_2	23	1.5	0.98-2.1	46	1.5	1.2-2.8
Dis. Solids	25	214	135-285	38	160	130-225
Spec. Conductance (micromhos/cm)	48	393	245-585	116	310	220-485
pH (pH units)	38		7.4-8.9	84		7.4-9.1
Alkalinity	37	125	105-155	82	105	100-120
Ca	23	39	32-45	46	33	32-44
Mg	37	15	11-19	82	10	8-19
Cl	31	19	5.3-36	81	8.3	5.3-23
SO_4	24	29	16-43	50	22	16-53
Phenols (micrograms per liter)	63	3	ND-10	118	1	ND-8

ND - not detectable at sensitivity of test. See Table 2.

TABLE 15

CHEMICAL RESULTS
AMMONIA AND NITRATE NITROGEN
LAKE MICHIGAN HARBORS, 1962-1963
AVERAGES BY SEASONS

Harbor	NH_3-N (mg/l)			NO_3-N (mg/l)		
	Spring	Summer	Fall	Spring	Summer	Fall
Indiana	0.11	1.3	2.0	0.06	0.17	0.23
Calumet	0.19	0.47	0.29	0.07	0.14	0.19
Chicago	NS	0.08	0.07	NS	0.10	0.09
Milwaukee	0.78	NS	1.3	0.10	NS	0.18

NS - not sampled.

TABLE 16

CHEMICAL RESULTS
DISSOLVED OXYGEN AND TOTAL SOLUBLE PHOSPHATE
LAKE MICHIGAN HARBORS, 1962-1963
AVERAGES BY SEASONS

Harbor	DO (mg/l)			Total Soluble PO_4 (mg/l)		
	Spring	Summer	Fall	Spring	Summer	Fall
Indiana	3.3	2.0	NS	0.04	0.05	NS
Calumet	9.6	7.9	NS	0.04	0.06	NS
Chicago	NS	8.0	12	NS	0.04	0.06
Milwaukee	12	NS	8.7	0.21	NS	0.59

NS - not sampled.

TABLE 17

CHEMICAL RESULTS
DISSOLVED OXYGEN AND PERCENT SATURATION
LAKE MICHIGAN HARBORS, 1962-1963
AVERAGES BY SEASONS

Harbors	Season	DO (mg/l)		Percent Saturation	
		Minimum	Maximum	Minimum	Maximum
Indiana	Spring	2.2	10	22	99
	Summer	0.4	3.4	4.2	39
	Fall	NS	NS	NS	NS
Calumet	Spring	9.2	10	89	97
	Summer	6.8	8.8	77	95
	Fall	NS	NS	NS	NS
Chicago	Spring	NS	NS	NS	NS
	Summer	7.8	8.1	86	89
	Fall	9.0	13	94	110
Racine	Spring	NS	NS	NS	NS
	Summer	NS	NS	NS	NS
	Fall	11	12	90	101
Milwaukee	Spring	8.2	15	77	138
	Summer	NS	NS	NS	NS
	Fall	5.3	11	47	96

NS - not sampled.

TABLE 18

CHEMICAL RESULTS
PHENOLS
LAKE MICHIGAN HARBORS 1962-1963
AVERAGES BY SEASONS

Harbors	Phenols (micrograms per liter)		
	Spring	Summer	Fall
Indiana	23	16	49
Indiana Harbor Canal	NS	50	163
Calumet	1	2	2
Chicago	NS	ND	ND
Racine	NS	NS	2
Milwaukee	2	NS	3
Milwaukee River	5	NS	NS

NS - not sampled.
ND - not detectable at the sensitivity of test. See Table 2.

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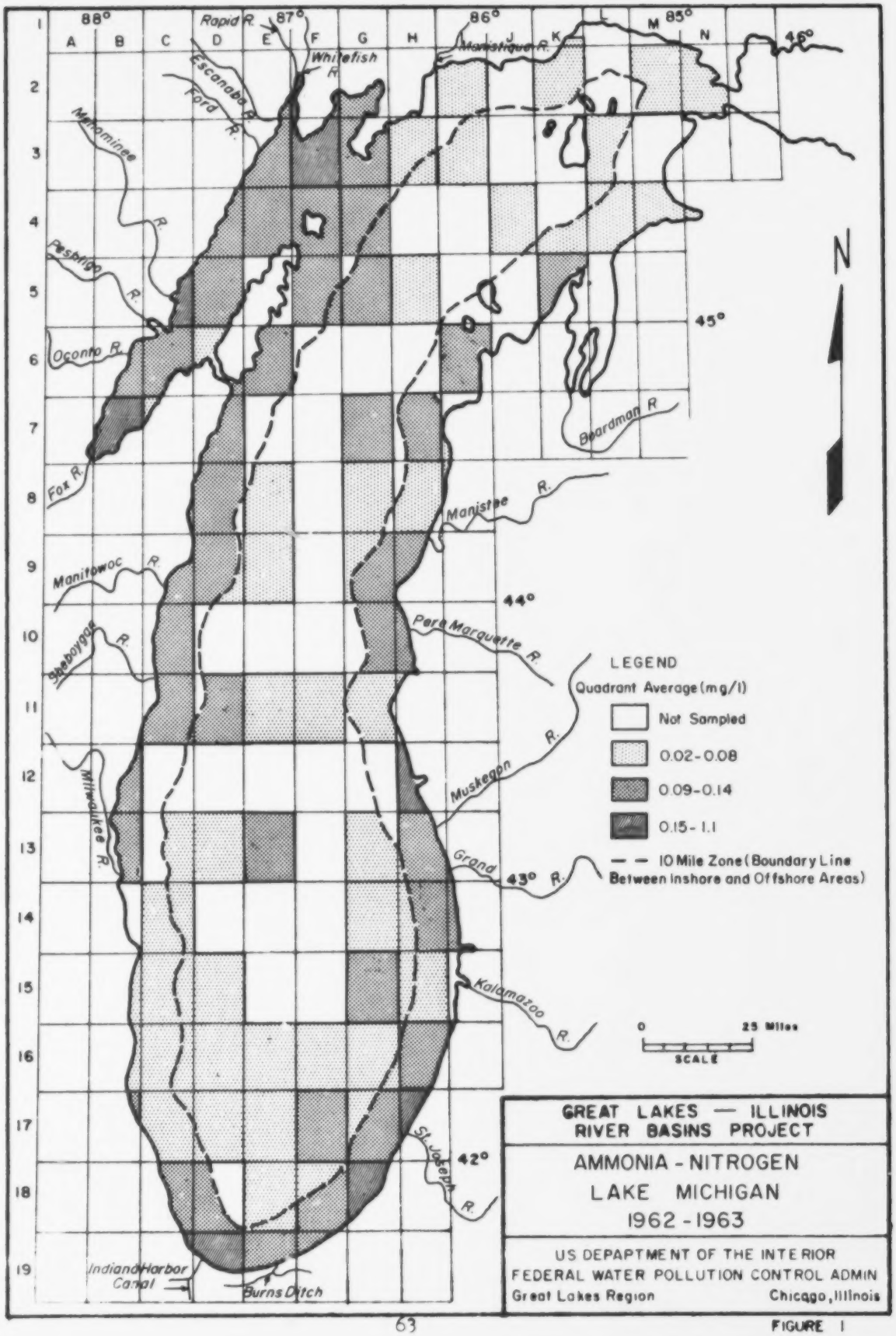
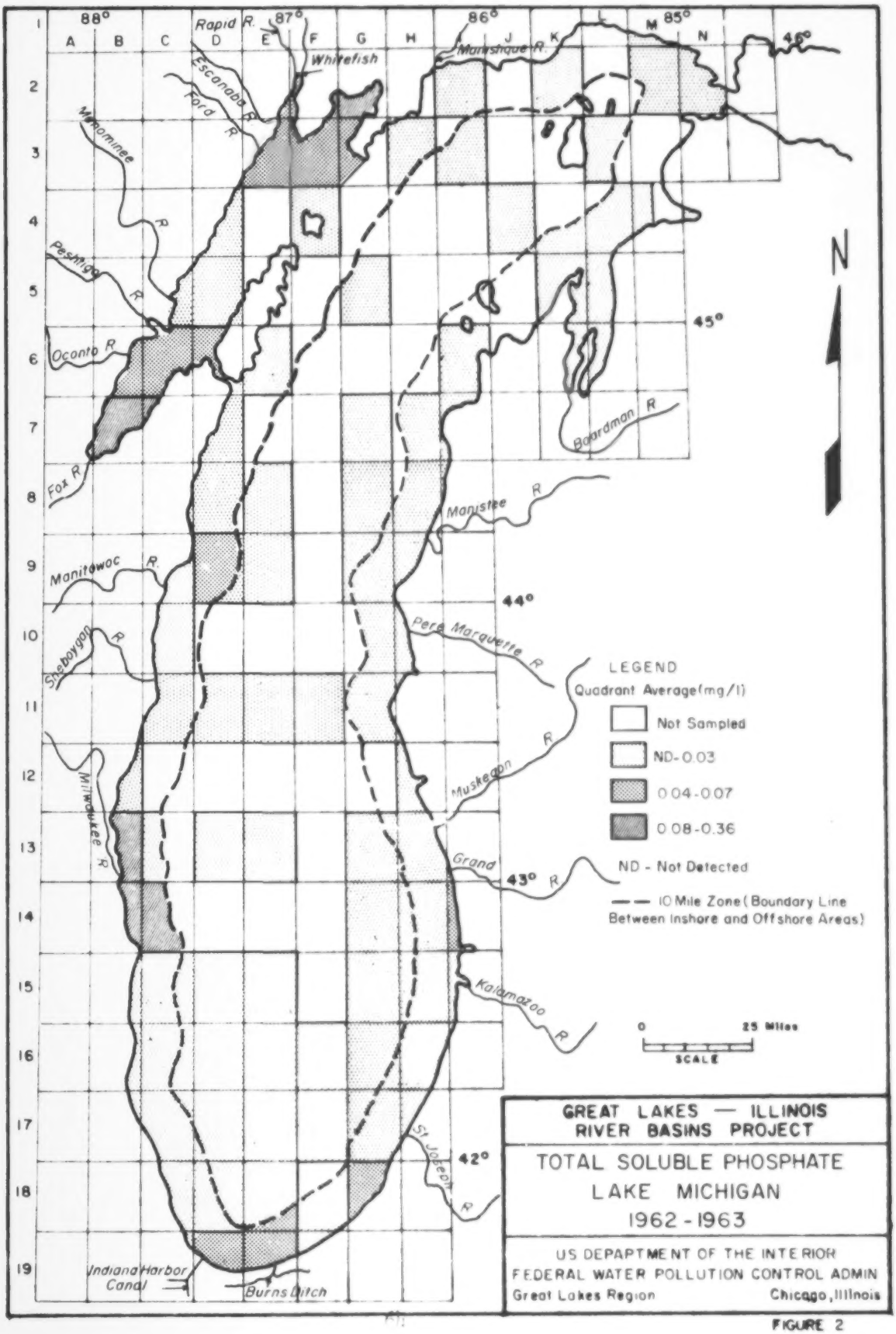


GREAT LAKES — ILLINOIS RIVER BASINS PROJECT

AMMONIA - NITROGEN
LAKE MICHIGAN
1962 - 1963

US DEPAPTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMIN
Great Lakes Region Chicago, Illinois

FIGURE 1

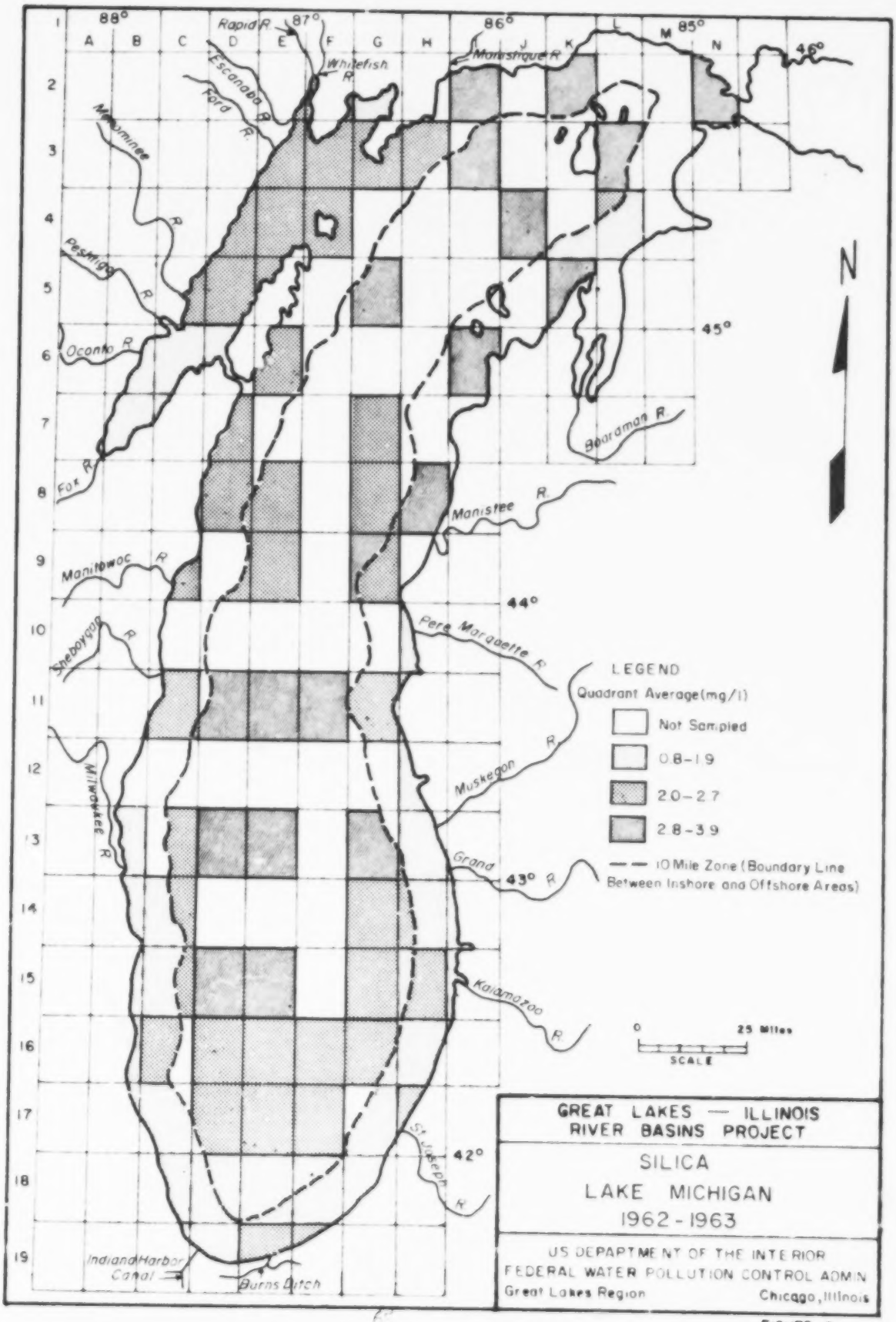


GREAT LAKES — ILLINOIS RIVER BASINS PROJECT

TOTAL SOLUBLE PHOSPHATE
LAKE MICHIGAN
1962 - 1963

US DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMIN
Great Lakes Region Chicago, Illinois

FIGURE 2



GREAT LAKES — ILLINOIS RIVER BASINS PROJECT

SILICA

LAKE MICHIGAN

1962 - 1963

US DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMIN
Great Lakes Region Chicago, Illinois

FIGURE 3

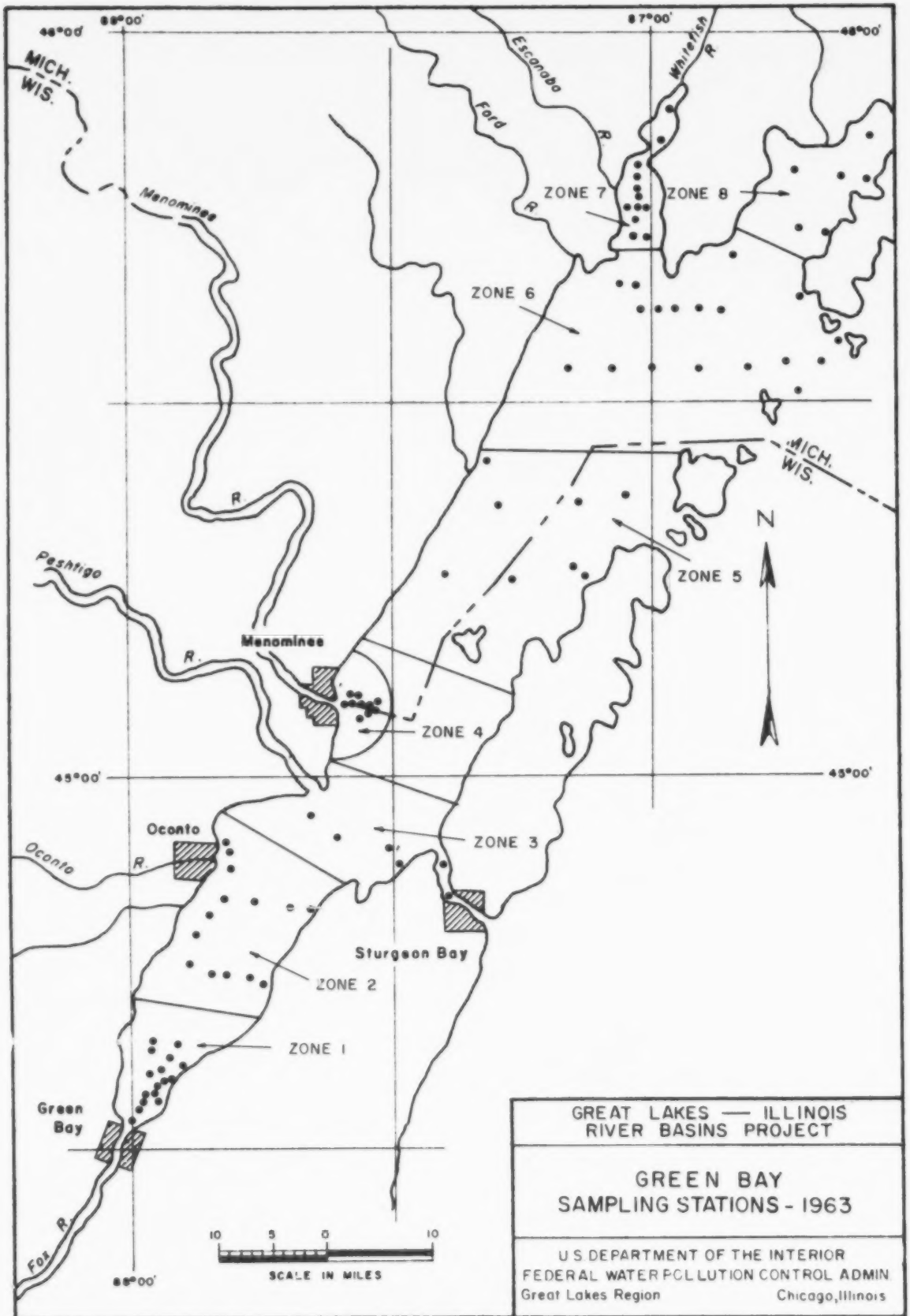

88°00'
87°00'
45°00'
MICH.
WIS.
Escanaba R.
Whitefish R.
Ford R.
Menominee R.
Peshtigo R.
Oconto R.
Fox R.
ZONE 1
ZONE 2
ZONE 3
ZONE 4
ZONE 5
ZONE 6
ZONE 7
ZONE 8
Menominee
Oconto
Sturgeon Bay
Green Bay
N
10 5 0 10
SCALE IN MILES
GREAT LAKES — ILLINOIS RIVER BASINS PROJECT
GREEN BAY
SAMPLING STATIONS - 1963
U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMIN
Great Lakes Region
Chicago, Illinois

FIGURE 4

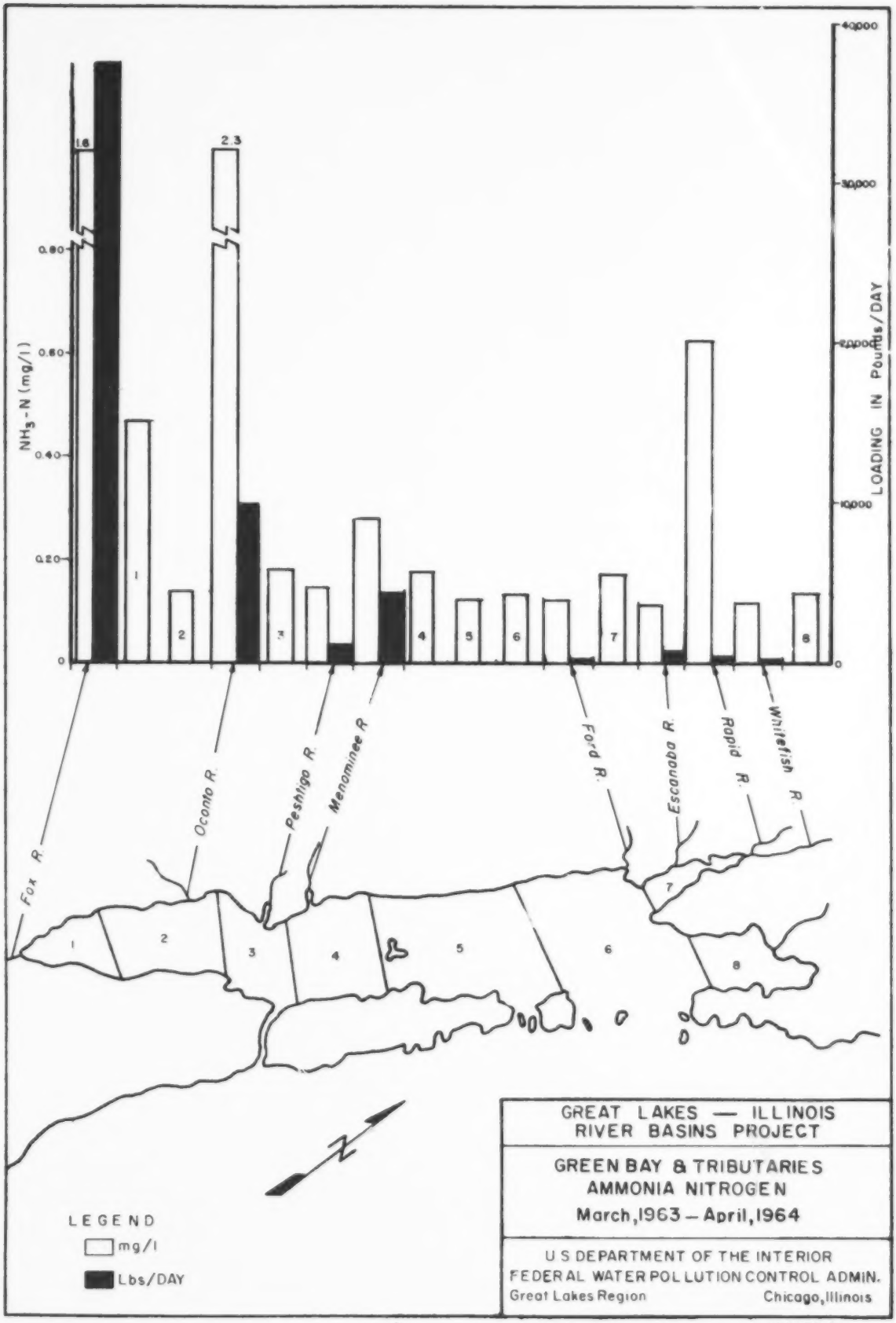

1.6
2.3
0.80
0.60
0.40
0.20
0
NH_3-N (mg/l)
40000
30000
20000
10000
0
LOADING IN Pounds/DAY
1
2
3
4
5
6
7
8
Fox R.
Oconto R.
Peshtigo R.
Menominee R.
Ford R.
Escanaba R.
Rapid R.
Whitefish R.
LEGEND
mg/l
Lbs/DAY
GREAT LAKES — ILLINOIS RIVER BASINS PROJECT
GREEN BAY & TRIBUTARIES
AMMONIA NITROGEN
March, 1963 – April, 1964
U S DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMIN.
Great Lakes Region
Chicago, Illinois

FIGURE 5

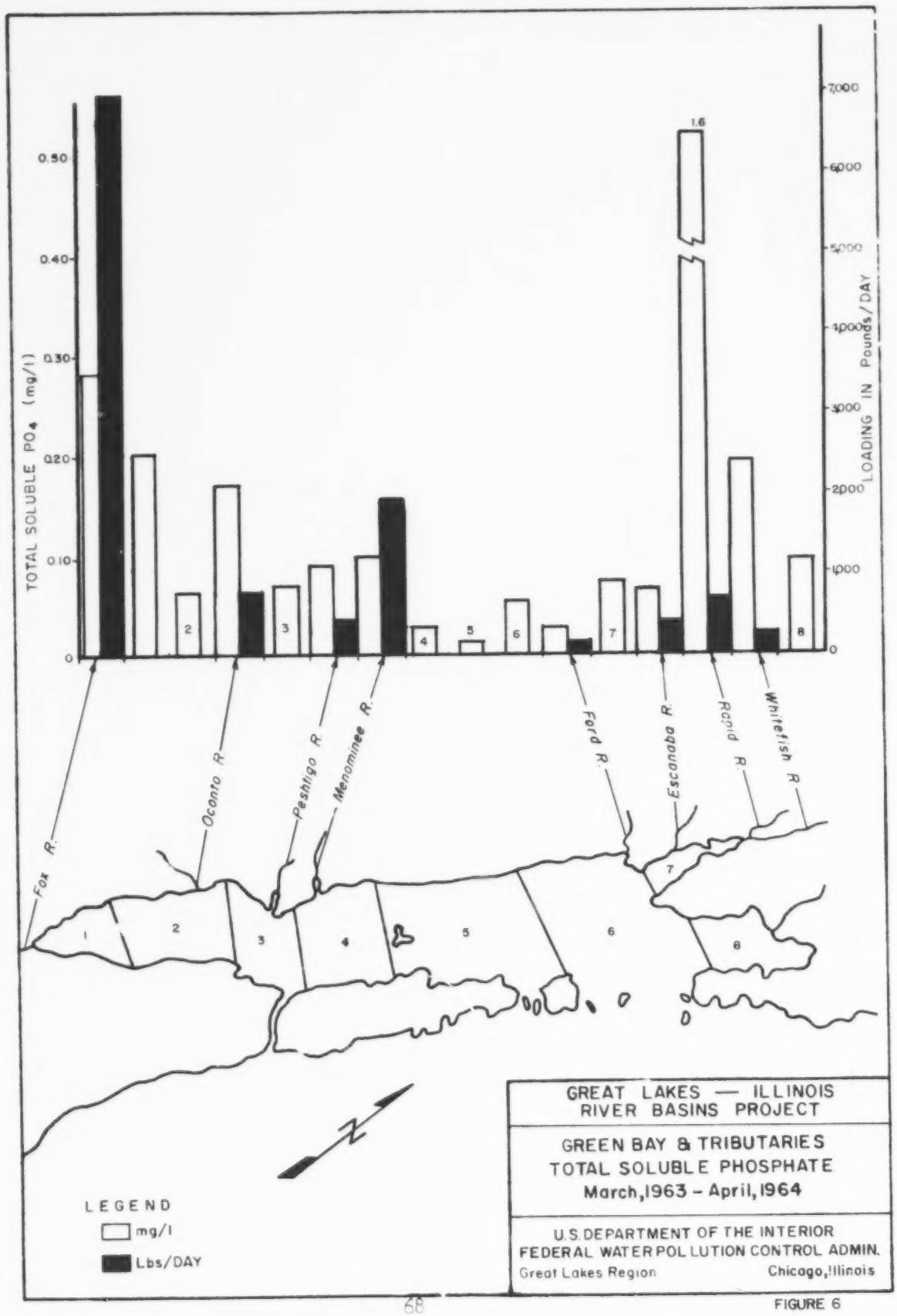

TOTAL SOLUBLE PO4 (mg/l)
0.50
0.40
0.30
0.20
0.10
0
LOADING IN Pounds/DAY
7000
6000
5000
4000
3000
2000
1000
0
1.6
1
2
3
4
5
6
7
8
Fox R.
Oconto R.
Peshtigo R.
Menominee R.
Ford R.
Escanaba R.
Rapid R.
Whitefish R.
LEGEND
mg/l
Lbs/DAY
GREAT LAKES — ILLINOIS RIVER BASINS PROJECT
GREEN BAY & TRIBUTARIES
TOTAL SOLUBLE PHOSPHATE
March, 1963 - April, 1964
U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMIN.
Great Lakes Region
Chicago, Illinois

FIGURE 6

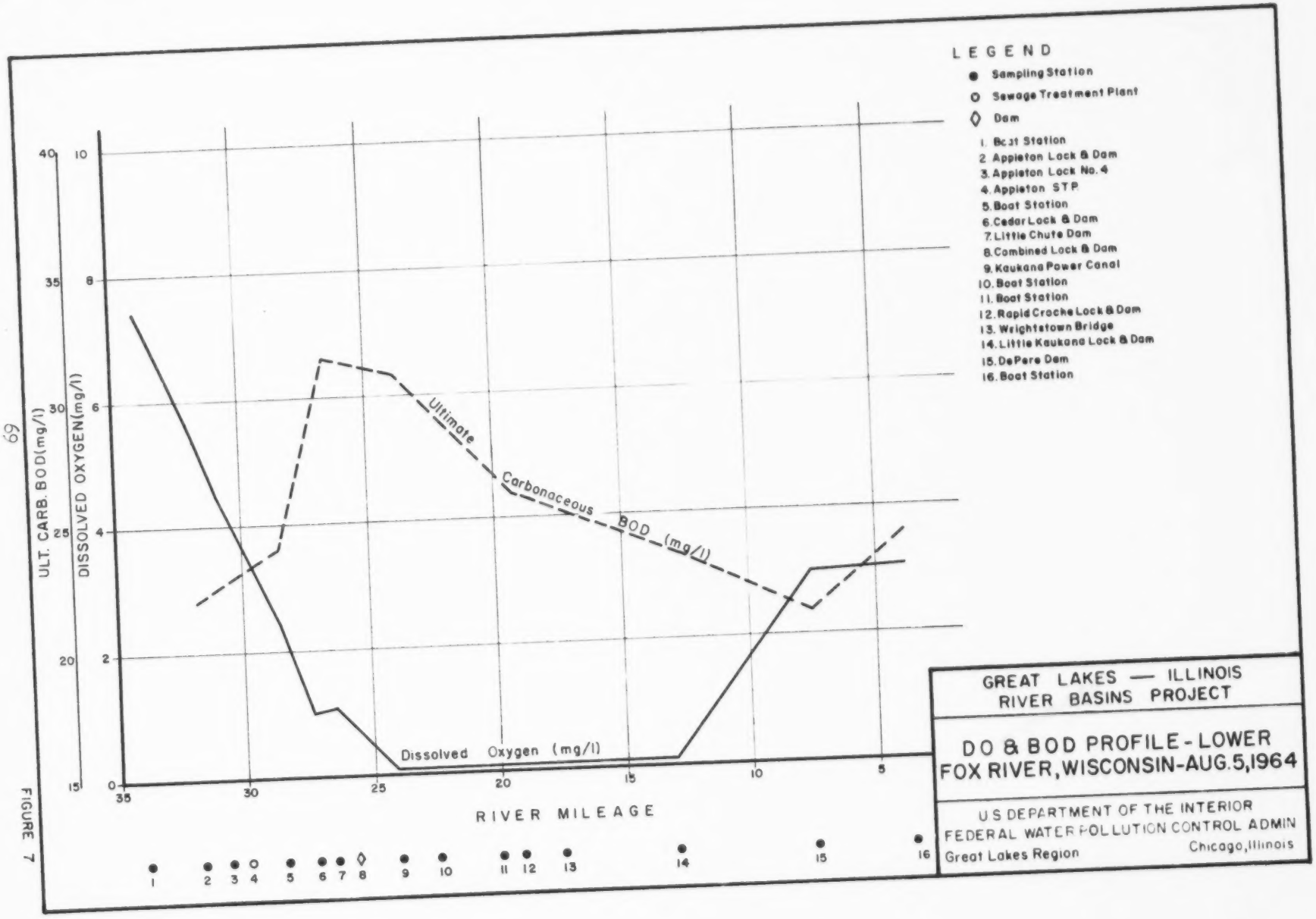
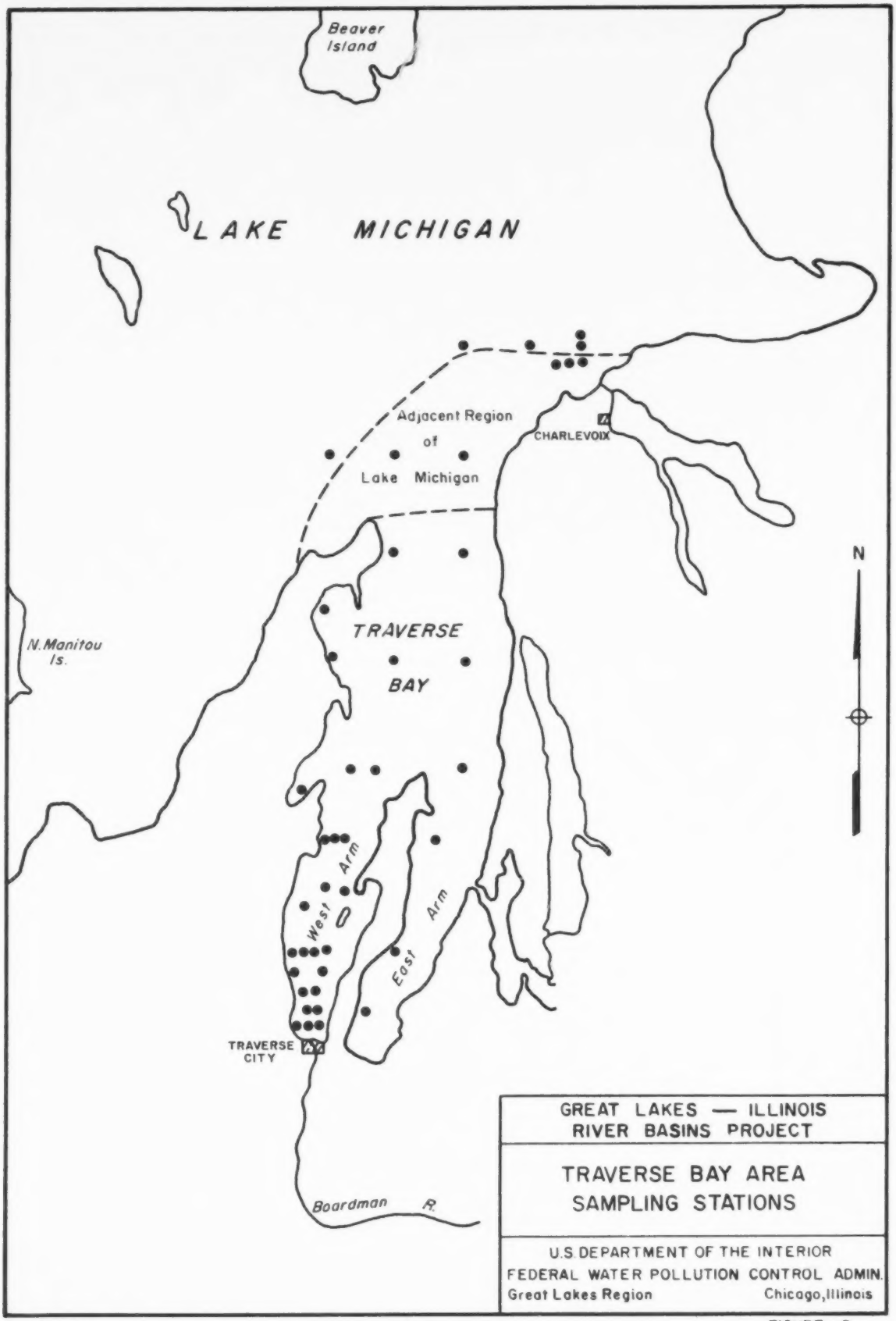

LEGEND
Sampling Station
Sewage Treatment Plant
Dam
1. Boat Station
2. Appleton Lock & Dam
3. Appleton Lock No. 4
4. Appleton STP
5. Boat Station
6. Cedar Lock & Dam
7. Little Chute Dam
8. Combined Lock & Dam
9. Kaukana Power Canal
10. Boat Station
11. Boat Station
12. Rapid Croche Lock & Dam
13. Wrightstown Bridge
14. Little Kaukana Lock & Dam
15. DePere Dam
16. Boat Station
ULT. CARB. BOD (mg/l)
DISSOLVED OXYGEN (mg/l)
Ultimate Carbonaceous BOD (mg/l)
Dissolved Oxygen (mg/l)
RIVER MILEAGE
GREAT LAKES — ILLINOIS RIVER BASINS PROJECT
DO & BOD PROFILE - LOWER FOX RIVER, WISCONSIN-AUG. 5, 1964
U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMIN
Great Lakes Region
Chicago, Illinois

FIGURE 7



GPO 806-484-4

FIGURE 8

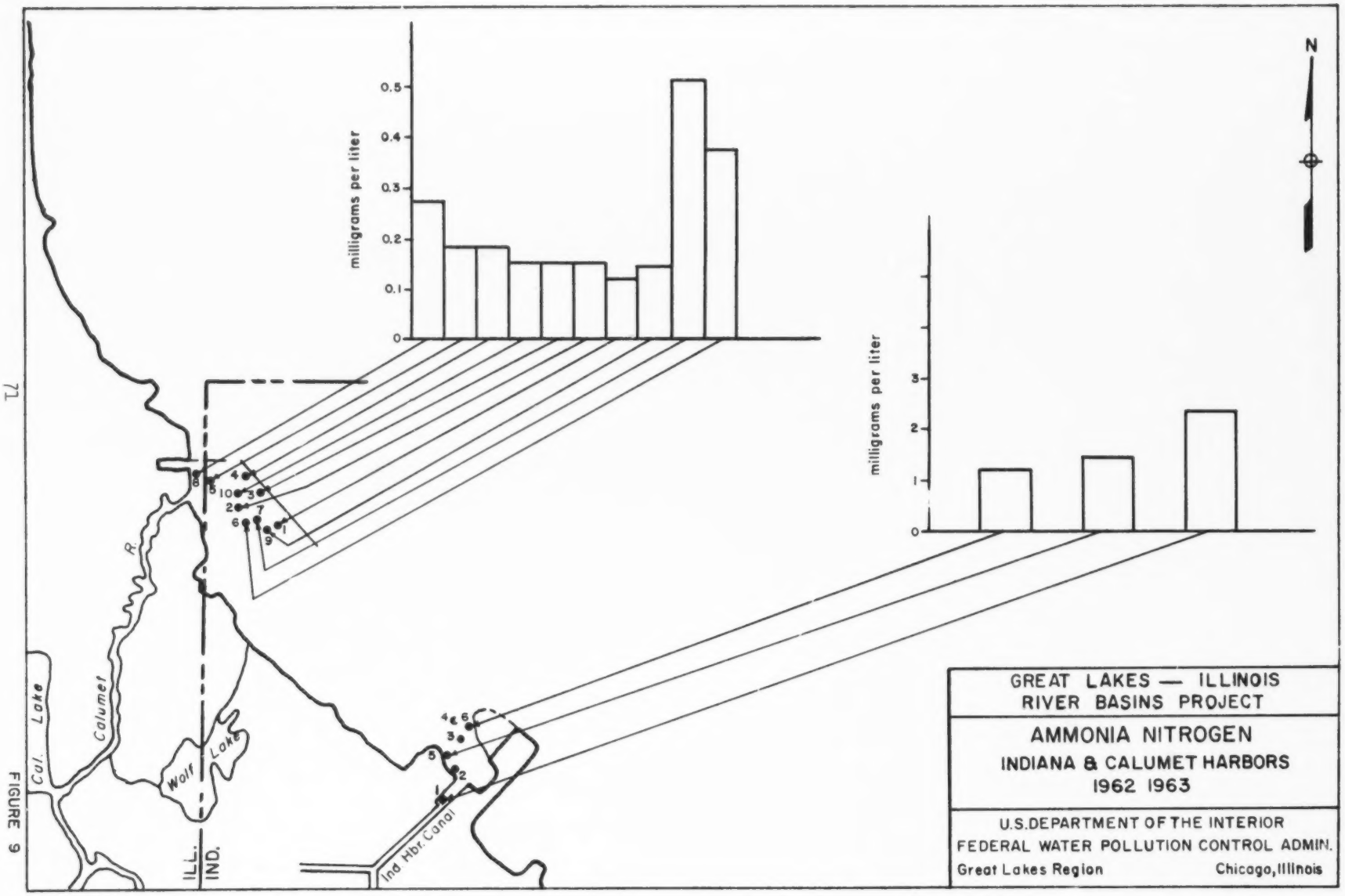

milligrams per liter
0.5
0.4
0.3
0.2
0.1
0
milligrams per liter
3
2
1
0
N
Cal. Lake
Calumet R.
Wolf Lake
ILL.
IND.
Ind Hbr. Canal
GREAT LAKES — ILLINOIS
RIVER BASINS PROJECT
AMMONIA NITROGEN
INDIANA & CALUMET HARBORS
1962 1963
U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMIN.
Great Lakes Region
Chicago, Illinois

FIGURE 9

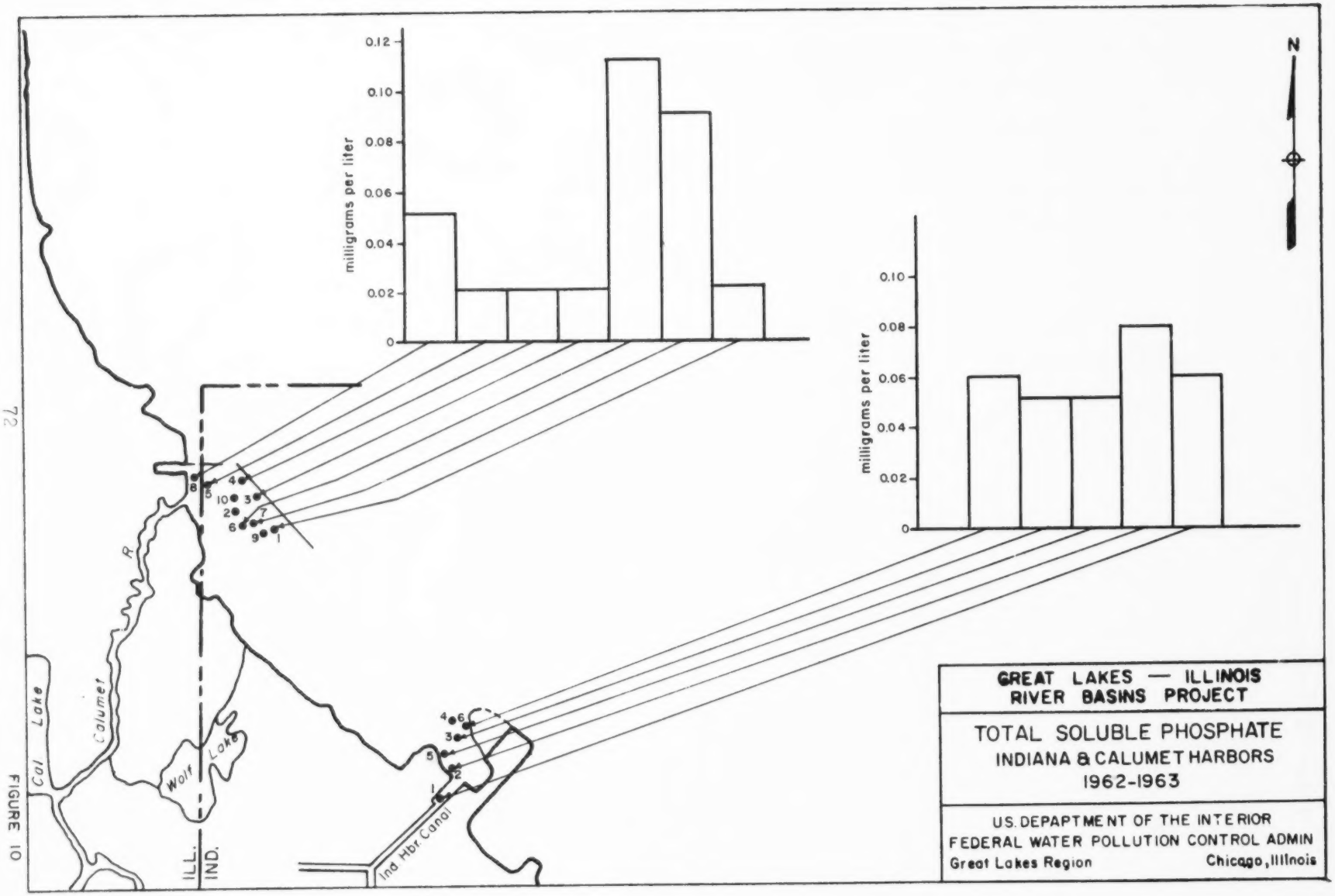

0.12
0.10
0.08
0.06
0.04
0.02
0
milligrams per liter
0.10
0.08
0.06
0.04
0.02
0
milligrams per liter
N
Cal Lake
Calumet R.
Wolf Lake
ILL.
IND.
Ind Hbr Canal
GREAT LAKES — ILLINOIS
RIVER BASINS PROJECT
TOTAL SOLUBLE PHOSPHATE
INDIANA & CALUMET HARBORS
1962-1963
US. DEPAPTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMIN
Great Lakes Region
Chicago, Illinois

FIGURE 10

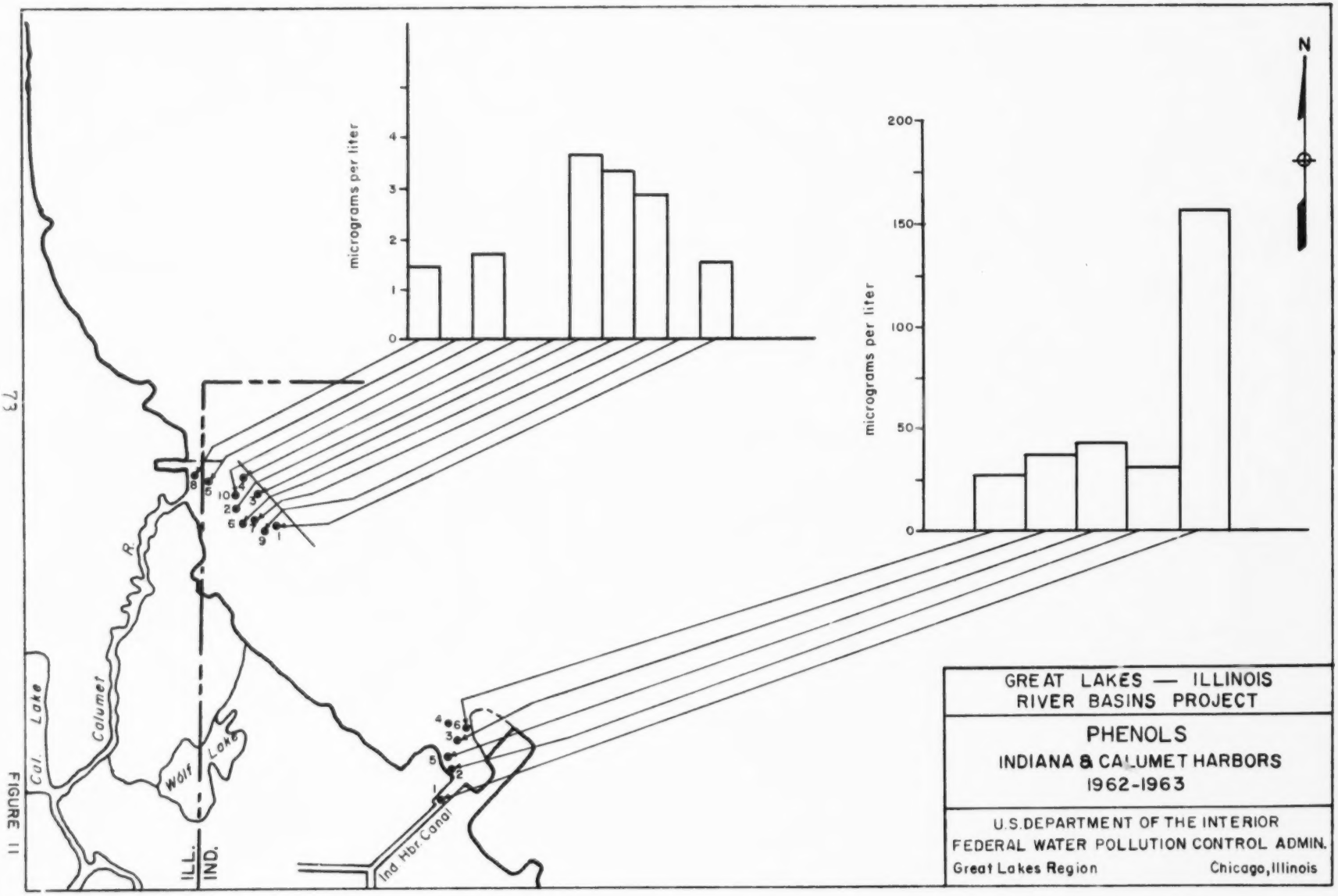

micrograms per liter
0
1
2
3
4
micrograms per liter
0
50
100
150
200
N
Col. Lake
Calumet R.
Wolf Lake
ILL.
IND.
Ind Hbr Canal
GREAT LAKES — ILLINOIS
RIVER BASINS PROJECT
PHENOLS
INDIANA & CALUMET HARBORS
1962-1963
U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMIN.
Great Lakes Region
Chicago, Illinois

FIGURE 11

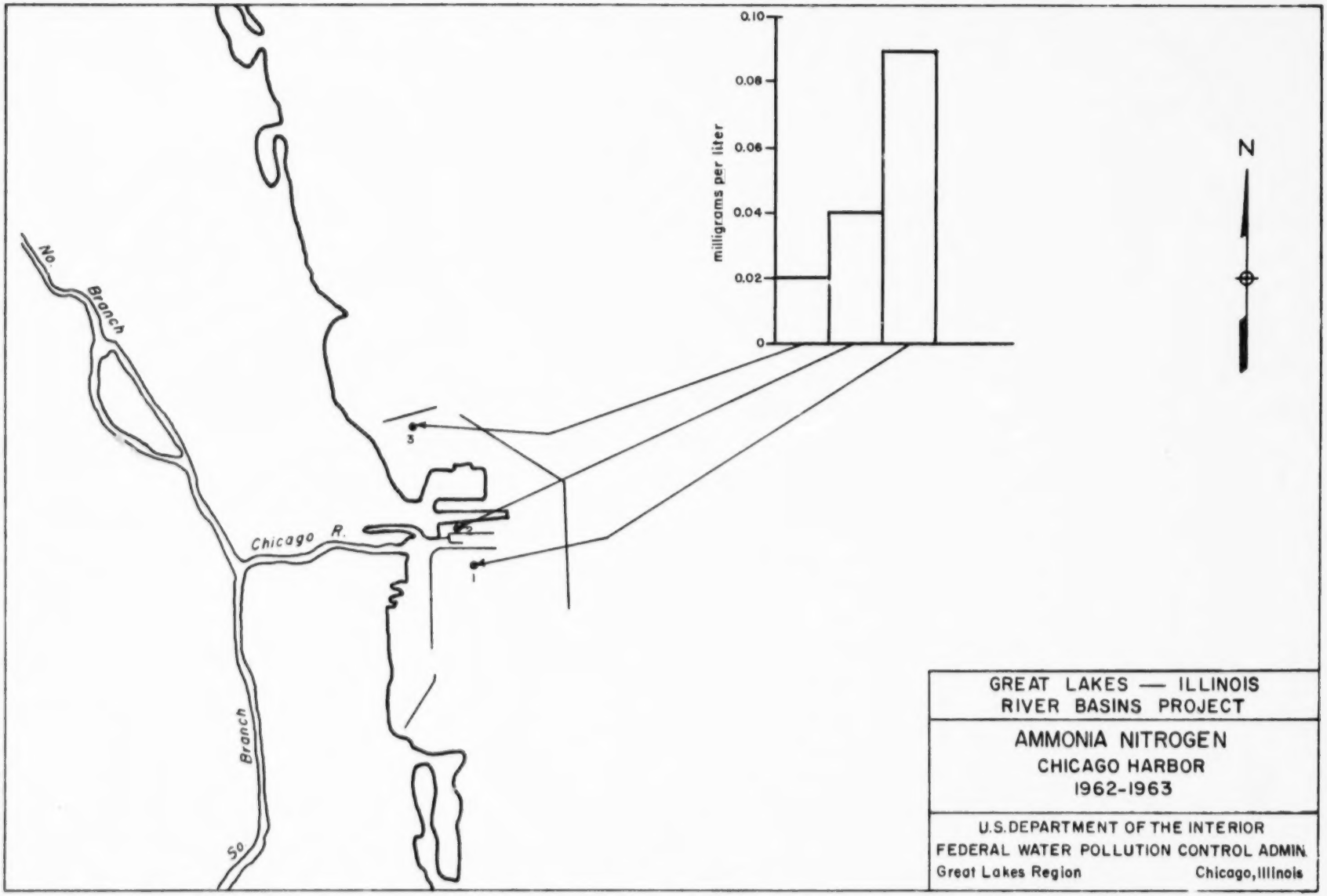

0.10
0.08
0.06
0.04
0.02
0
milligrams per liter
N
No. Branch
Chicago R.
So. Branch
3
2
1
GREAT LAKES — ILLINOIS
RIVER BASINS PROJECT
AMMONIA NITROGEN
CHICAGO HARBOR
1962-1963
U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMIN.
Great Lakes Region
Chicago, Illinois

FIGURE 12

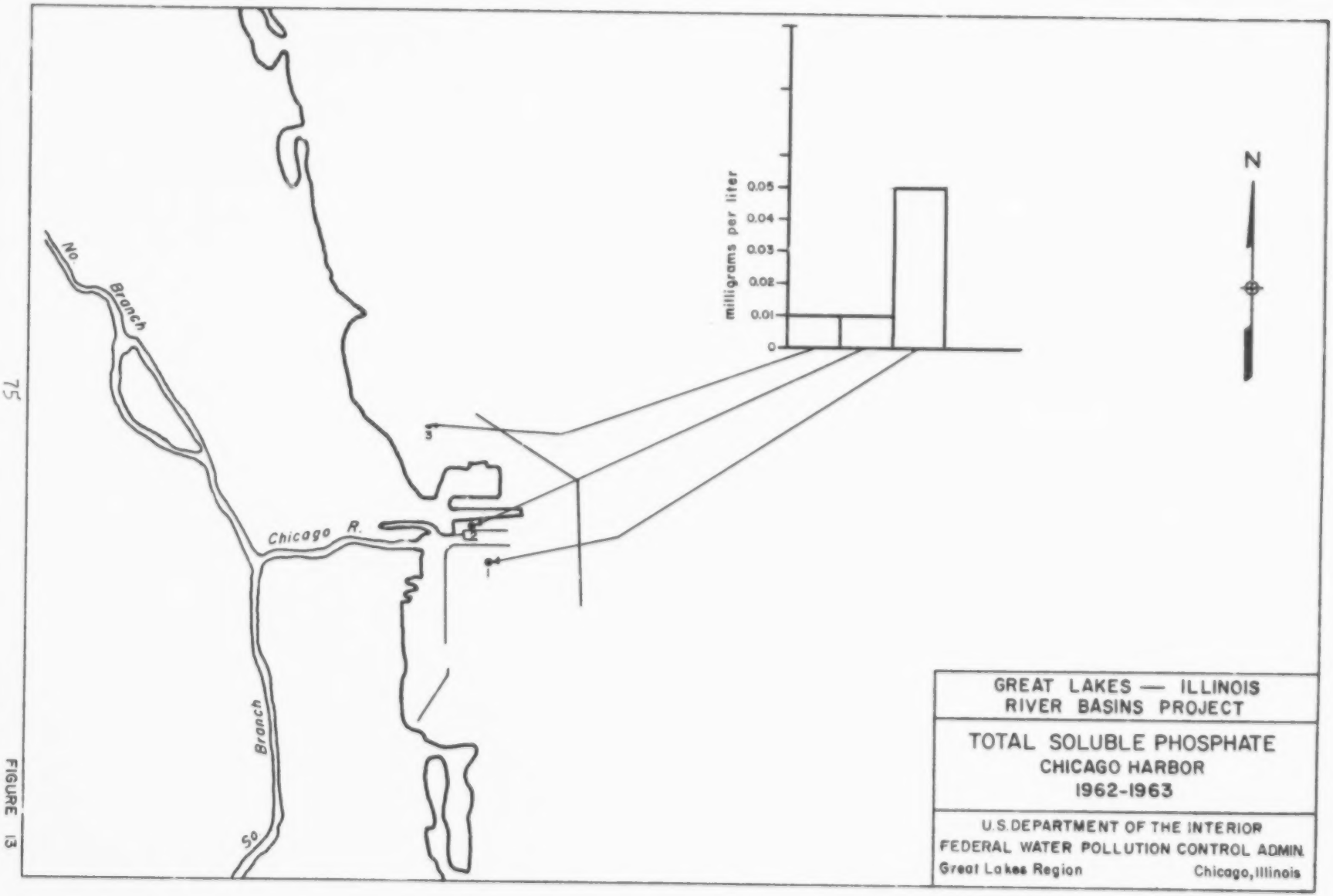
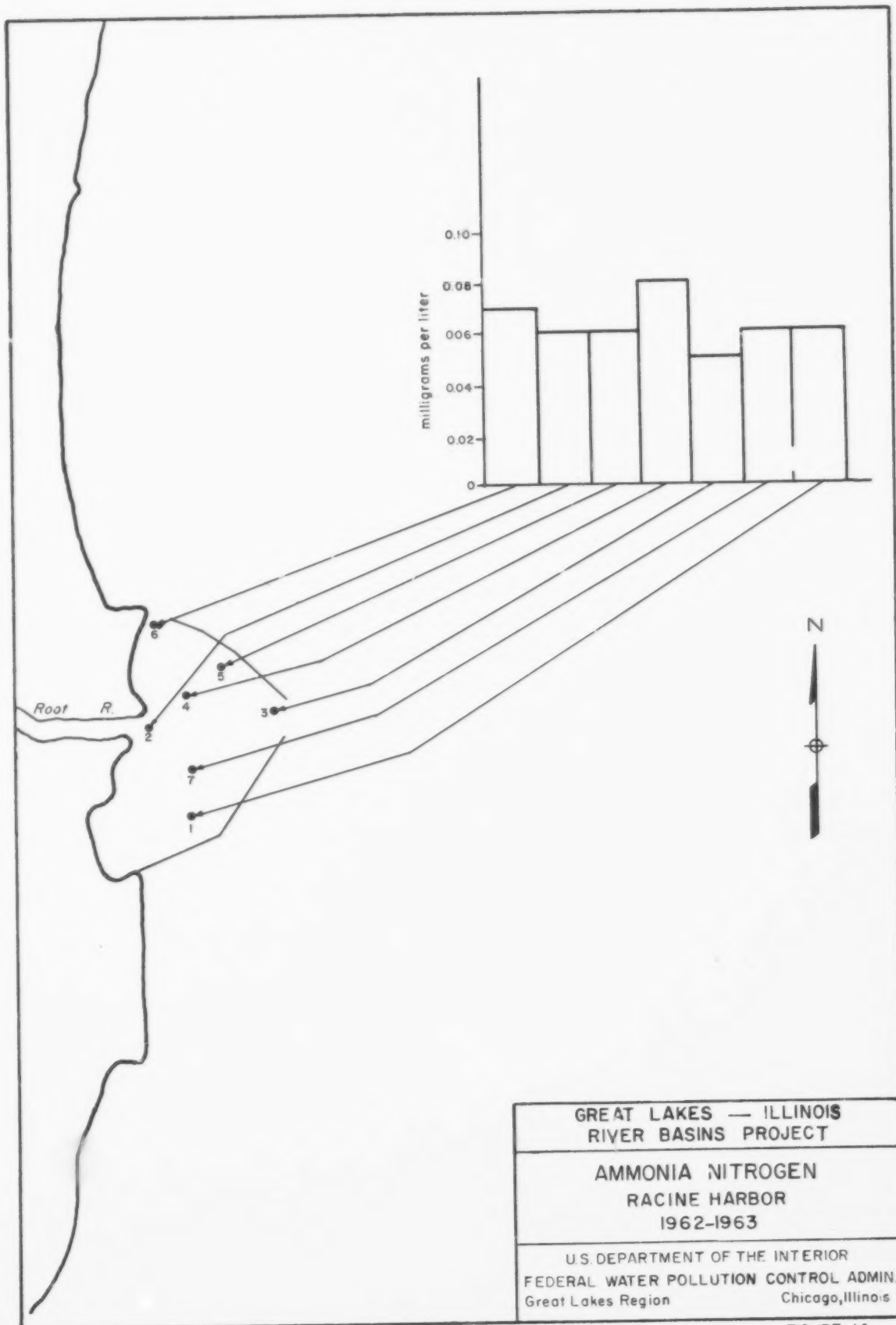

No. Branch
Chicago R.
So. Branch
milligrams per liter
0.05
0.04
0.03
0.02
0.01
0
N
GREAT LAKES — ILLINOIS
RIVER BASINS PROJECT
TOTAL SOLUBLE PHOSPHATE
CHICAGO HARBOR
1962-1963
U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMIN.
Great Lakes Region
Chicago, Illinois

FIGURE 13

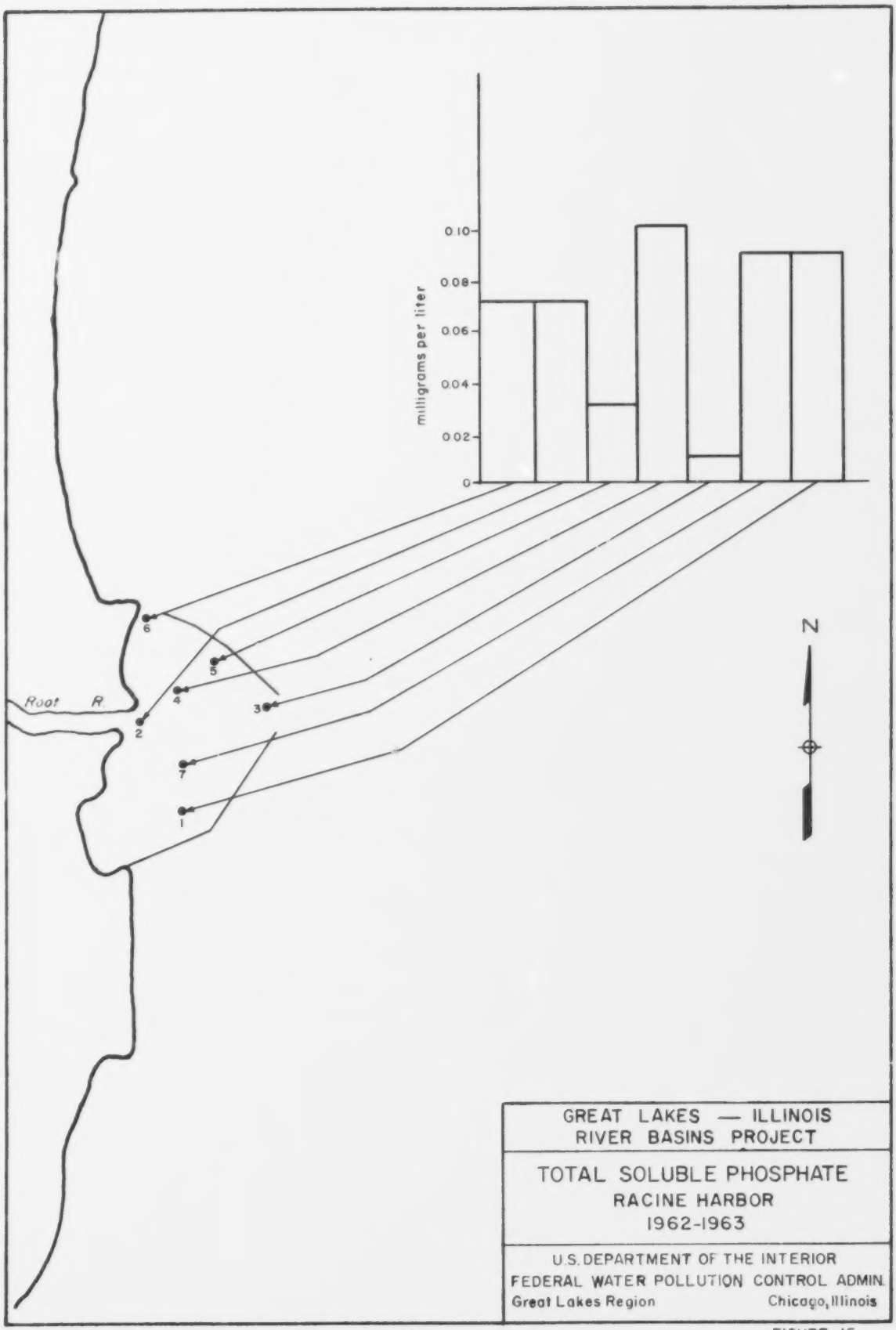


GREAT LAKES — ILLINOIS
RIVER BASINS PROJECT

AMMONIA NITROGEN
RACINE HARBOR
1962-1963

U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMIN.
Great Lakes Region Chicago, Illinois

FIGURE 14

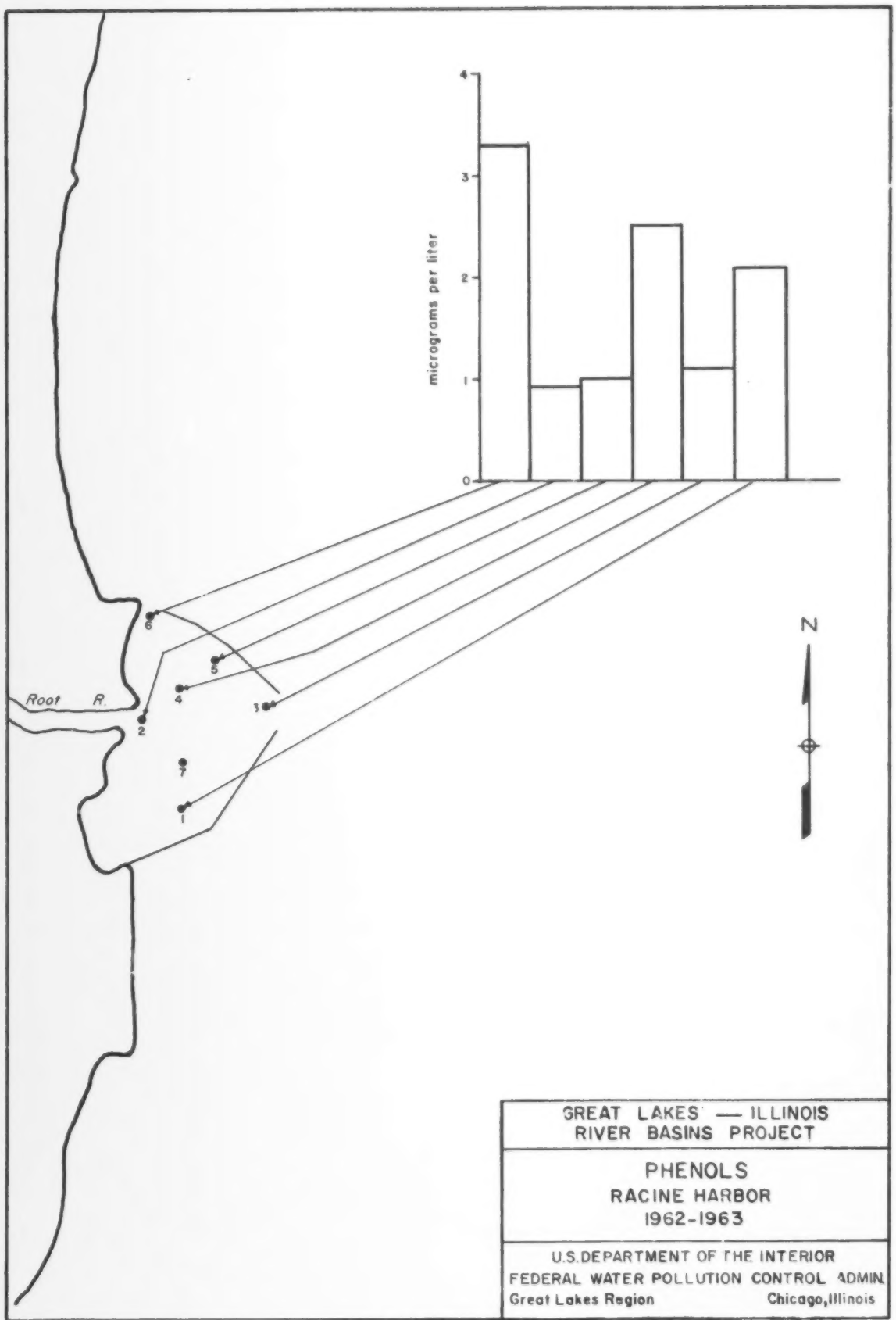


GREAT LAKES — ILLINOIS
RIVER BASINS PROJECT

TOTAL SOLUBLE PHOSPHATE
RACINE HARBOR
1962-1963

U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMIN.
Great Lakes Region Chicago, Illinois

FIGURE 15



GREAT LAKES — ILLINOIS
RIVER BASINS PROJECT

PHENOLS
RACINE HARBOR
1962-1963

U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMIN.
Great Lakes Region Chicago, Illinois

GPO 806-484-3

FIGURE 16

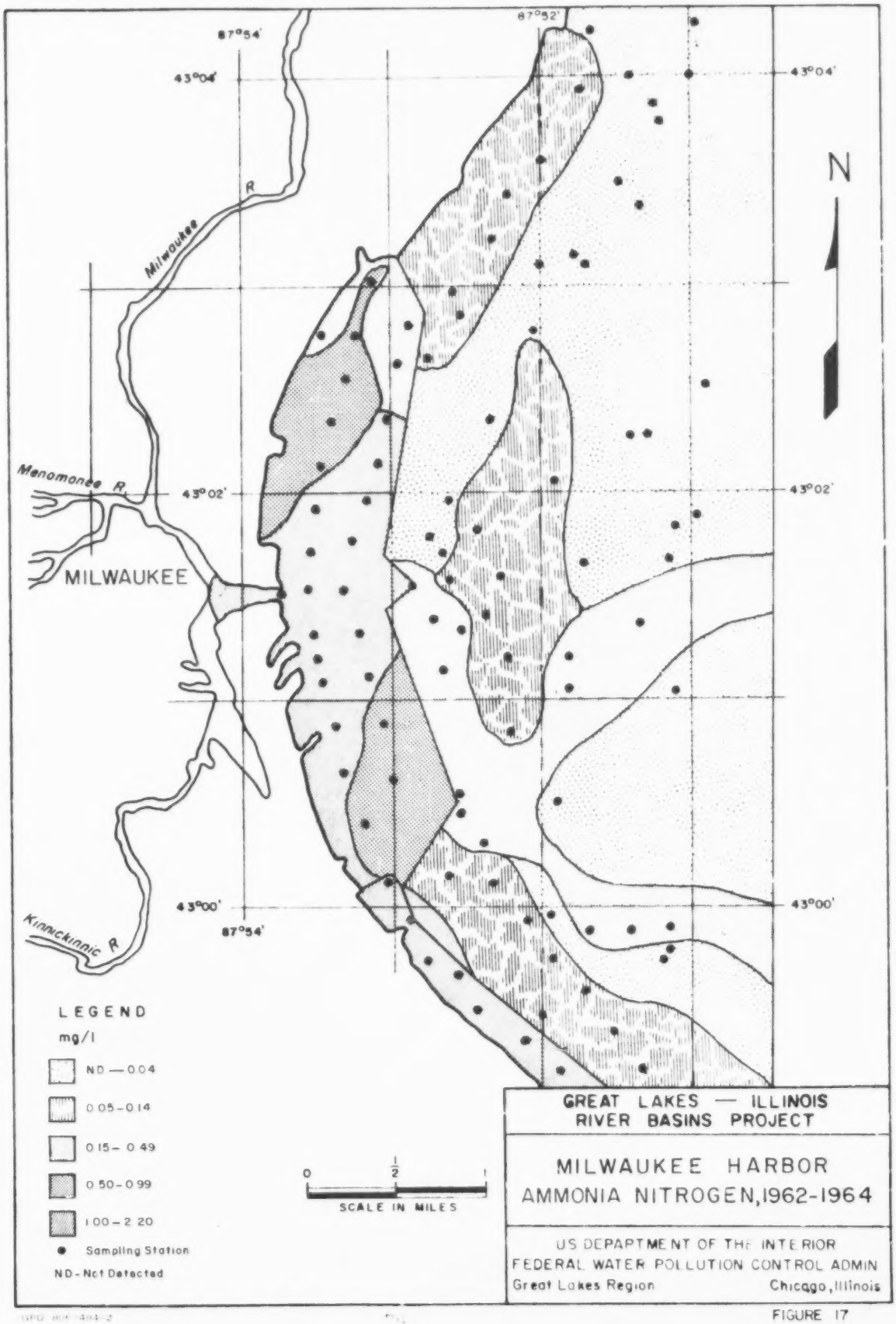

87°54'
87°52'
43°04'
43°02'
43°00'
N
Milwaukee R.
Menomonee R.
MILWAUKEE
Kinnickinnic R.
LEGEND
mg/l
ND — 0.04
0.05 – 0.14
0.15 – 0.49
0.50 – 0.99
1.00 – 2.20
Sampling Station
ND - Not Detected
0
1/2
1
SCALE IN MILES
GREAT LAKES — ILLINOIS RIVER BASINS PROJECT
MILWAUKEE HARBOR
AMMONIA NITROGEN, 1962-1964
US DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMIN
Great Lakes Region
Chicago, Illinois

FIGURE 17

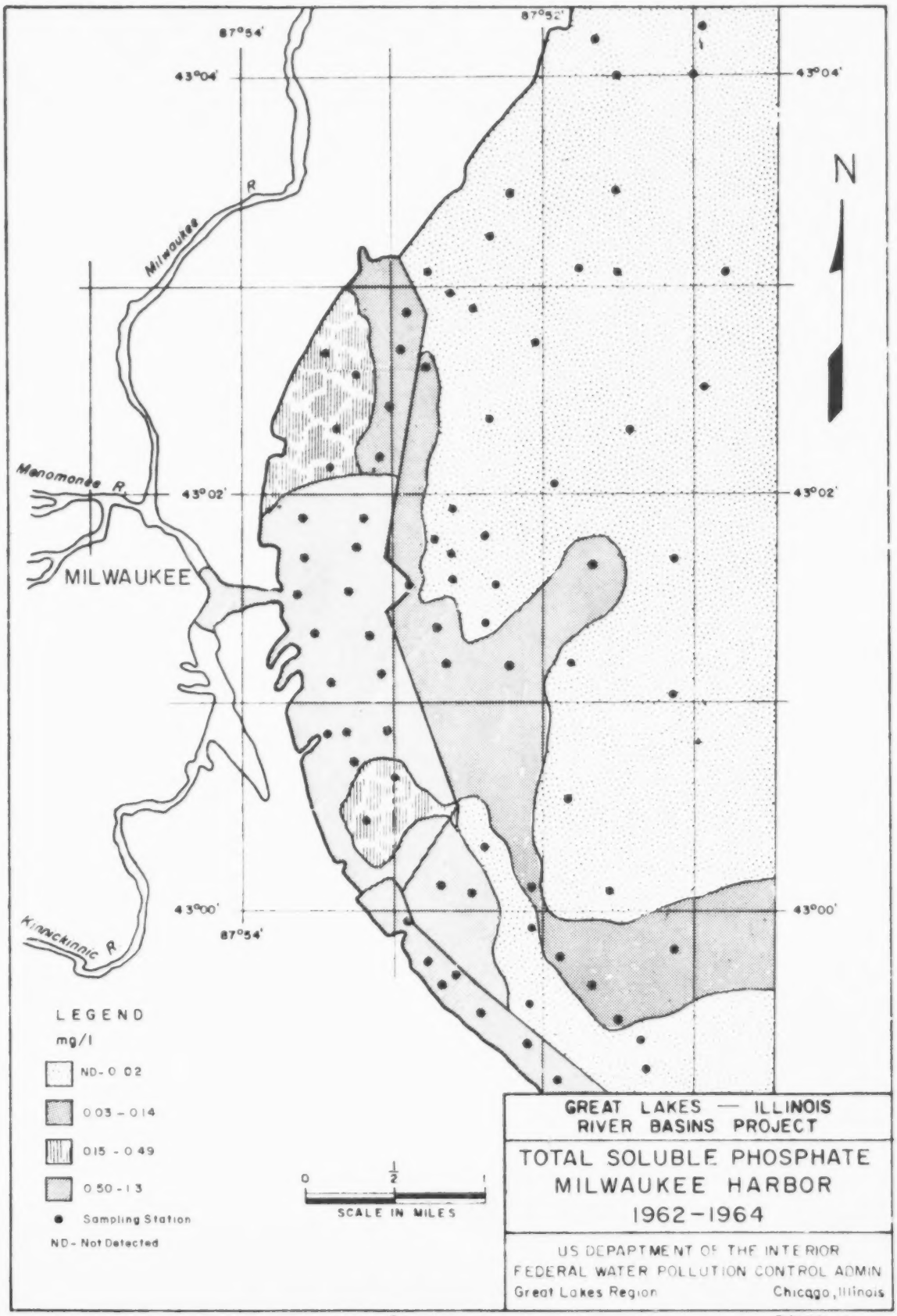

87°54'
87°52'
43°04'
43°02'
43°00'
N
Milwaukee R.
Menomonee R.
MILWAUKEE
Kinnickinnic R.
LEGEND
mg/l
ND- 0 02
0 03 - 0 14
0 15 - 0 49
0 50 - 1 3
Sampling Station
ND - Not Detected
0
1/2
1
SCALE IN MILES
GREAT LAKES — ILLINOIS RIVER BASINS PROJECT
TOTAL SOLUBLE PHOSPHATE
MILWAUKEE HARBOR
1962 - 1964
US DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMIN
Great Lakes Region
Chicago, Illinois

FIGURE 18

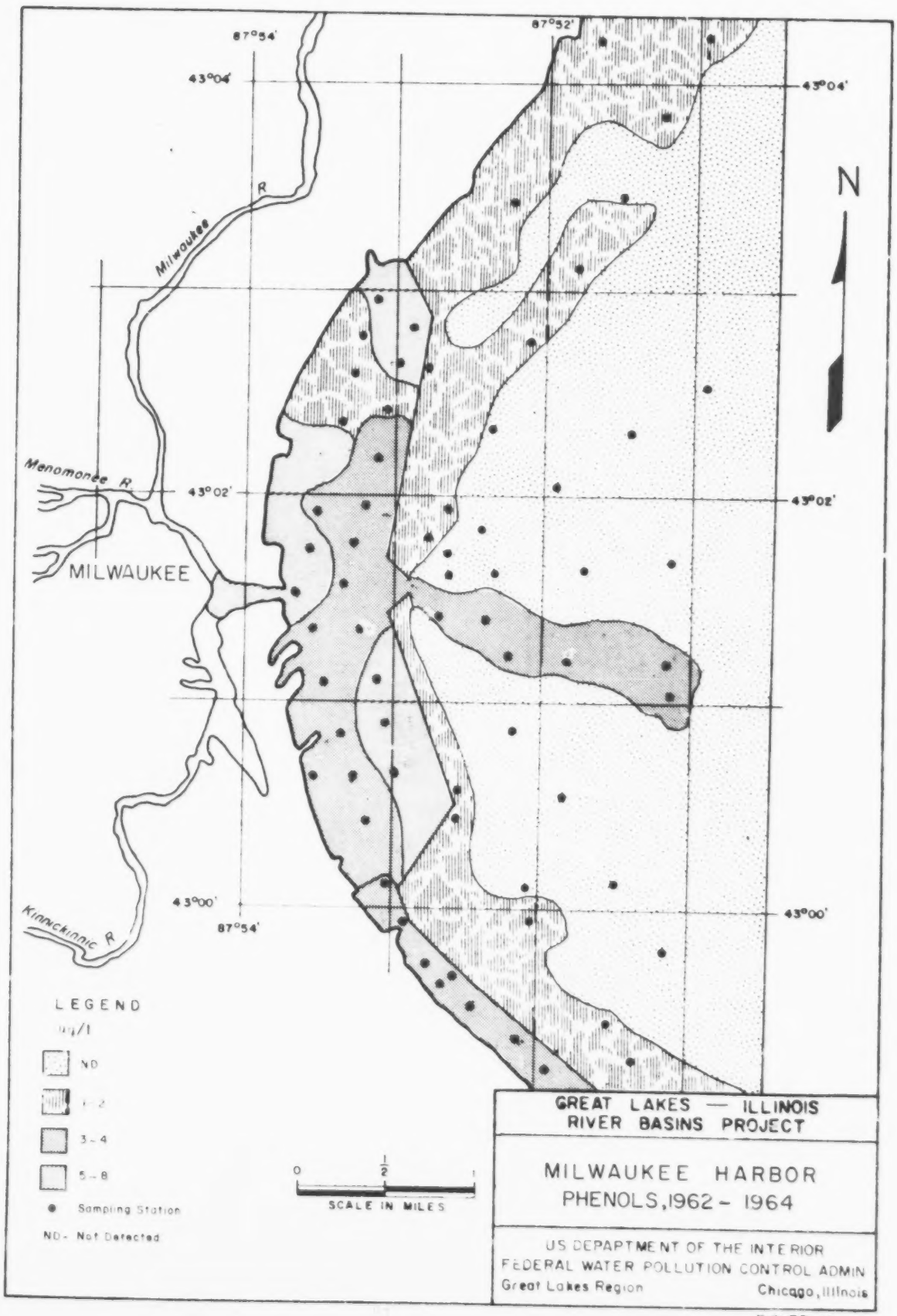

87°54'
87°52'
43°04'
43°02'
43°00'
N
Milwaukee R.
Menomonee R.
MILWAUKEE
Kinnickinnic R.
LEGEND
µg/l
ND
1-2
3-4
5-8
Sampling Station
ND- Not Detected
0
1/2
1
SCALE IN MILES
GREAT LAKES — ILLINOIS RIVER BASINS PROJECT
MILWAUKEE HARBOR
PHENOLS, 1962 - 1964
US DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMIN
Great Lakes Region
Chicago, Illinois

FIGURE 19

ERRATA

The following corrections should be made in the "Lake Michigan Basin Report of Physical and Chemical Quality Conditions."

1. Page 17 - 3rd paragraph - change (Table 5) to (Table 3).
2. " 17 - 4th " " 2.7 mg/l to 2.5 mg/l.
3. " 18 - 1st " " Table 2 to Table 3.
4. " 18 - last " " 0.03 mg/l to 0.04 mg/l.
   " 0.01 mg/l to 0.02 mg/l.
5. " 19 - 2nd " " 72 micrograms per liter to 32.
6. " 21 - 2nd " " 0.06 mg/l to 0.07 mg/l.
   " 0.15 mg/l to 0.14 mg/l.
7. " 21 - 3rd " " 23 tons to 123 tons.
8. " 24 - 5th " " 156 micrograms per liter to 159.
9. " 24 - 6th " Delete the words "lead, and" in last sentence and change "were" to "was".
10. " 26 - 1st " Delete the words "lead, and" in first sentence and change "were" to "was".
11. " 27 - 4th " Change ND-0.05 mg/l to ND-0.04 mg/l.
12. " 27 - 5th " " 0.49-1.3 mg/l to 0.50-1.3 mg/l.
13. " 27 - last " " 0.49-1.3 mg/l to 0.50-1.3 mg/l.
    " ND-0.03 mg/l to ND-0.02 mg/l.
14. " 38 - last line " 0.02 to 0.002.
15. " 45 - Table 7b Manistique River - MBAS - Change 0.18 to 0.08
    " 820 to 364
    Cu,Ni,Zn - Change NS to 0.08-0.08

January 31, 1968

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